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THE EFFECTIVENESS OF SPECIFICALLY DESIGNED FILTER MEDIA TO REDUCE NITRATE AND ORTHOPHOSPHATE IN STORMWATER RUNOFF

by

MIKHAL MOBERG, E.I.
B.S. University of Central Florida, 2008

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil and Environmental Engineering
in the College of Engineering and Computer Science
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2008

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ABSTRACT

Throughout Central Florida surface water and ground water are decreasing in quantity and quality in part because of excess Nitrate and Phosphorus nutrients. Stormwater runoff serves as a medium for transport of Nitrate and Phosphorus to surface water and ground water. The goal of this experiment is assess the Nitrate and Phosphorus removal in stormwater using select media.

The results of a literature search, batch test experimentation and column test experimentation are used to determine an optimal media blend that may be implemented in detention ponds to reduce Nitrate and Phosphorus. The extensive literature search revealed 32 different media that may be used to remove Nitrate and Phosphorus. Each potential media was qualitatively and quantitatively evaluated based on 5 criteria: 1) relevance, 2) permeability, 3) cost, 4) availability in Florida, and 5) additional environmental benefit. The top 7 performing media: Florida peat, sandy loam, woodchips, crushed oyster shell; crushed limestone, tire crumb and sawdust were selected for batch test experimentation. The aerobic conditions in batch test experimentation prohibited the growth of denitrifying bacteria, therefore media mixes were selected for column test experimentation based on Ammonia and Orthophosphate concentrations. Batch test experimentation showed the most effective media to be 50% sand, 30% tire crumb, 20% sawdust by weight (media mix 1) and 50% sand, 25% sawdust, 15% tire crumb, 10% limestone by weight (media mix 2). Media mix 1, media mix 2 and a control are tested in column test experimentation, where the control is site soil from Hunters Trace development in Ocala, Florida. Column test experimentation models a dry detention pond where water passes through a 48 inch unsaturated zone then a 48 inch saturated zone. To test Nitrate and Orthophosphate removal potential, pond water augmented with Nitrate (0.38, 1.26, 2.5 mg/L NO_3-N) and Orthophosphate (0.125, 0.361, 0.785 mg/L PO_4-P) was pumped into the columns. Media mix 1 and media mix 2 outperformed the control in both Nitrate and Orthophosphate removal. Media mix 1 and media mix 2 had Nitrate removal efficiencies ranging from 60% to 99% and the control had Nitrate removal efficiencies ranging from 38%-80%. Media mix 1 and media mix 2 averaged Orthophosphate removal efficiencies ranging from approximately 42% to 67%. For every run in every influent Orthophosphate concentration the saturated control added Orthophosphate to the water. The Nitrate and Orthophosphate removal performances for media mix 1 and media mix 2 could not be directly compared because of different influent saturated nutrient concentrations.

ACKNOWLEDGMENTS

I would like to thank my committee members Dr. Wanielista, Dr. Chang and Dr. Chopra. I would especially like to thank Dr. Wanielista for providing me this opportunity and guiding me to achieve my goals. Thanks to Ammerin Makkeasorn for help with construction of experimental columns. I would also like to thank Elizabeth Henderson for her help with batch test experimentation. Thanks also to Lisa Naujock for her help with material characterization on this project.

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CHAPTER ONE: INTRODUCTION

Introduction

Ground water and surface water are an essential part of nature that creates and maintains both human and animal life. Ground water and surface water are used for many purposes such as drinking, irrigation and recreation. Surface water may also be used to recharge ground water supplies. Conservation and management of ground water and surface water is important to prevent habitat destruction and maintain proper ecological balance. Central Florida groundwater supplies are decreasing in volume and quality as a result of increasing population and land use activities. Ground water is consumed faster than it can be recharged and polluted by industrial and farming waste products. As groundwater supplies continue to decrease the quantity and quality of surface water will become increasingly relevant.

Ground water quality and surface water quality is dependant on a variety of factors such as stormwater runoff, land use activities, air quality and the presence of industry. Rainfall and stormwater runoff function as a medium of transport for nutrients and pollutants from land into ground water and surface water. Land use activities such as livestock farming and agricultural farming may contribute animal waste and excess fertilizer into surface water bodies. Nutrients within fertilizers and animal wastes may percolate into ground water which may provide for diminished groundwater quality. Air pollution may be carried into the ground water and surface water through rainfall and stormwater runoff. Wastewater treatment facilities and industrial sources may contribute to the degradation of ground water and surface water quality by directly introducing nutrients and or pollution into the receiving water bodies.

Replacing pervious areas such as forests and grasslands with impervious areas such as shopping malls and roadways may increase surface water quantity and reduce surface water quality. Pervious areas allow stormwater to percolate into the ground. The natural environment will filter and cleanse the stormwater and deliver it to a surface water body or a groundwater system. In the absence of rainfall impervious areas may accumulate pollution. Rainfall and stormwater runoff displace the pollution and nutrients that accumulate on impervious surfaces. Pollutants and nutrients within stormwater runoff may impair ground water and surface water. Degradation of water quality and loss of habitat may result from the impairment of receiving water bodies.

Stormwater treatment is a primary concern when discussing ground water quality and surface water quality because of the potential destructive impact that impaired stormwater runoff may have on the water quality of the receiving water body. Various pollutants and nutrients such as metals, oils, Nitrates and Phosphorus may be carried within stormwater runoff and delivered to groundwater or other surface water bodies such as lakes, rivers and streams. The amount of pollution contributed by stormwater runoff into a receiving body may be relatively low or exceptionally high. Typically stormwater management controls called Best Management Practices (BMP’s) are used to control both quantity and quality of stormwater runoff. BMP’s are separated into 2 categories: structural and nonstructural. Structural BMP’s are treatment technologies that are physically constructed and include constructed wetlands, reactive filter media, ponds, pervious concrete, infiltration trench, vegetative filter strips and detention basins (North Carolina Division of Water Quality, 2007). Nonstructural BMP's include usage of native vegetation, addition or retention of trees throughout the watershed, decreasing impervious area, education and environmentally sound design (FDEP, 2008).

Problem Statement

Central Florida springs and lakes are currently suffering from reduced water quality caused by excess nutrients. The Nitrate concentrations within Central Florida springs have been increasing for approximately 50 years (USGS, 2008). In Silver Springs which is located near Ocala, Florida Nitrate concentrations have risen from 0.5 mg/L in the 1960's to approximately 1.0 mg/L in 2003 (Phelps, 2004). Lake Apopka and other lakes in Central Florida are negatively impacted by the presence of excess nutrients. The nutrient contamination that impairs Central Florida's springs and lakes is partially caused by nutrient rich stormwater runoff.

Excess Nitrogen loading within groundwater recharge boundaries may directly affect the Nitrate-Nitrite concentration within the spring. It can be seen in Figure 1 that excess Nitrogen within the recharge boundary permeates into the groundwater. The nutrient rich recharge follows the groundwater flow until it is released to the surface by a spring thus increasing the Nitrogen concentration of the spring water.

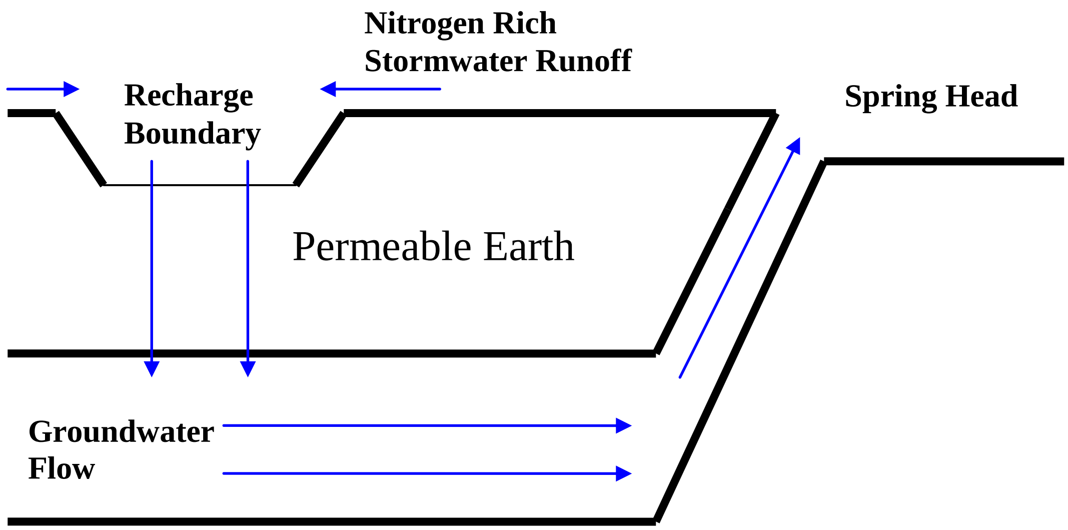

Figure 1: Stormwater Nitrogen Transfer

Nitrogen contamination within springs is seldom referred to as "Nitrogen contamination"; it is more commonly referred to as Nitrate or Nitrite contamination. Within nature Nitrogen is available in many forms. The surrounding environment will determine the form of Nitrogen that is present. The transition of Nitrogen from one phase to another is commonly referred to as the Nitrogen cycle. Direct interpretation of Figure 1 may lead the reader to believe that the Nitrogen species entering the recharge boundary is the same as the Nitrogen species exiting the spring head. This would be true if all of the Nitrogen entering the recharge boundary was in the form of Nitrate or Nitrite however that is not typically the situation. Stormwater runoff delivers Ammonia (NH_3) from fertilizer, animal waste and human waste to recharge boundaries. Organic materials combine with Ammonia to create ammonium (NH_4^+). In the presence of oxygen Nitro somas bacteria convert ammonium to Nitrite (NO_2^-) and Nitrobacter bacteria convert Nitrite to Nitrate (NO_3^-). Collectively these two reactions are called nitrification.

<u>Nitrification</u>

$NH_4^+ + 1.5O2 \Rightarrow 2H^+ + 2H_2O + NO_2^-$ (Equation 1)

$NO_2^- + 0.5O_2 \Rightarrow NO_3^-$ (Equation 2)

Figure 2 presents a schematic of nitrification relating excess waste and fertilizer to groundwater and spring contamination.

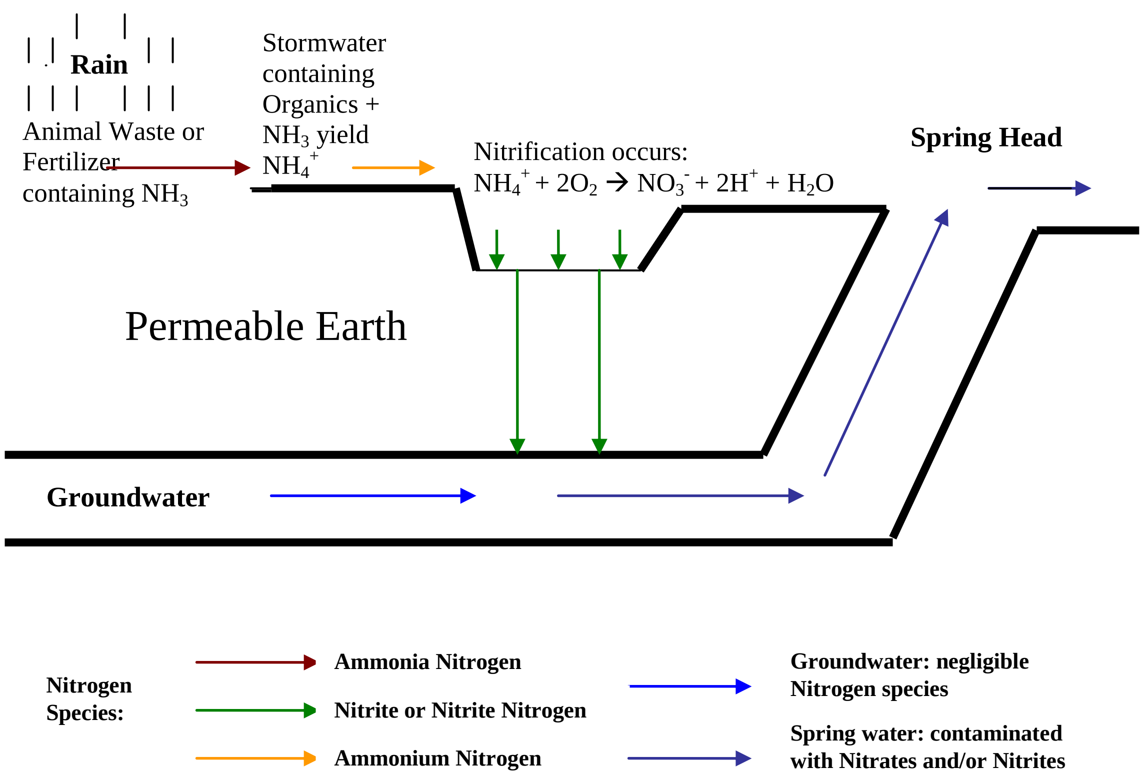

Figure 2: Nitrification of Wastes and Fertilizers

Elevated nutrient levels in ground water may cause health problems in children and may impair or destroy environmentally sensitive habitat. A percentage of Florida's drinking water comes from groundwater and excess levels of Nitrate in drinking water may cause blue baby syndrome in young children and infants (Knobeloch, 2000). High Nitrate and Phosphorus levels in ground water may promote algal growth which may degrade aesthetics and health of Florida's springs. Stormwater runoff pollutes and contaminates surface waters in the same way that it pollutes ground water. Ammonium becomes Nitrate through the process of nitrification which increases the Nitrate concentration of the surface water. Increased nutrient concentrations in surface waters may lead to excess plant and algal growth. Plant and algae growth continue until all available resources have been depleted. Plants and algae die and decay resulting in lower dissolved oxygen levels and overall water quality.

Objectives

The objective of the experiment is to reduce the amount of Nitrate and Phosphorus entering ground water and surface waters. Specifically Nitrate and Phosphorus reduction may be realized by creating filter media that reduce Nitrate and Phosphorus. The objective is accomplished through three stages: identification of potential stormwater filter media, batch test experimentation and column test experimentation. An extensive literature review is conducted to identify all potential stormwater filter media. Top performing media from the literature search are selected for batch test experimentation. The top performing media from batch test experimentation are selected for column test experimentation. Results of column test experimentation may provide a solution to the broad objective of Nitrate and Phosphorus reduction.

Limitations

The temperature during the batch test and column test remains fairly constant throughout experimentation at approximately 70 degrees Fahrenheit. Therefore the results of batch test experimentation and column test experimentation are based on a relatively small temperature range. Column test experimentation is limited to the selected media mixes. Only two different media mixes are tested during column test experimentation. Column test experimentation is limited to the selected influent Nitrate and Orthophosphate concentrations. The Nitrate and Orthophosphate concentrations used in column test experimentation are consistent with typical stormwater Nitrate and Orthophosphate concentrations. Column test experimentation is limited to a constant flow rate and therefore a constant retention time. Column test flow rates are comparable with wet pond infiltration rates.

CHAPTER TWO: BACKGROUND INFORMATION

Media Selection

Basic methodologies of nutrient removal are explored to promote understanding necessary for media selection. The mechanisms for Nitrogen removal and Phosphorus removal are very different. Nitrate is very soluble and usually does not sorb well to soil components during infiltration (Spalding and Kitchen, 1988). During infiltration Phosphorus tends to readily sorb onto many soils and media types (Crites, 1985).

Nitrate removal rates are directly influenced by the slow growing bacteria that govern nitrification and denitrification. Microorganisms that facilitate nitrification grow best at temperatures between 20°C and 25°C (Rittmann, 2000). Nitrification and denitrification are heavily dependent on stormwater pH because pH values less than 5.7 will inhibit nitrification (Rudd, 1988). The optimal pH range for nitrification and denitrification is between 7.5 - 8 and 7 – 8 (Rittmann, 2000). Optimal temperature for the denitrifiers was found to be between 10^{o}C and 25^{o}C. Nitrate removal occurs in an anaerobic environment located in the saturated zone when denitrifying bacteria convert Nitrate NO_3^- into Nitrogen gas N_2.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Phosphorus may be removed in either an aerobic or anaerobic environment and is removed through sorption onto soil media. However as the sorption sites fill, the Phosphorus removal decreases. Diminished Phosphorus removals occur because the cation exchange capacity of the soil or media is exceeded (White and Dornbush, 1988). To remove Phosphorus and Nitrogen, media must have the ability to sorb Phosphorus in the saturated and or unsaturated zone and provide the conditions necessary to grow and maintain nitrifying and denitrifying bacteria in the saturated zone.

The increasing importance of groundwater quality and surface water quality has contributed to the usage of new materials and methodologies for treating stormwater runoff. Many different types of materials have been tested as filter media; an intensive literature review conducted by a UCF research team indicated 32 different types of media may be used to reduce Nitrogen and or Phosphorus within stormwater runoff. Each potential media was qualitatively evaluated based on 5 criteria: 1) relevance, 2) permeability, 3) cost, 4) availability in Florida, and 5) additional environmental benefit. To assess overall performance quantitative rankings were assigned to each criterion. Seven were selected for batch test evaluation. To understand the media selection process, Table 1 shows a summary of all potential sorption media considered for this experiment. The media were assessed relative to the five criteria by assigning potential in five categories from excellent to poor. Table 2 shows a qualitative assessment of the potential of each media. Criteria 1 relevance was assessed using a numerical rating system with 5 being excellent potential, 4 very good potential, 3 good potential, 2 fair potential and 1 poor potential. Relevance measures the potential of media to remove Phosphorus from the unsaturated and saturated zone remove Nitrogen from the saturated zone. The mechanism of removal for Phosphorus in the unsaturated and saturated zone is hypothesized to be sorption. In this experiment Nitrogen removal is considered to be a biological process that takes place within an anaerobic or saturated environment. Permeability and cost were based on high, medium and low potentials which translate quantitatively into 5, 3 and 1. Availability in Florida and additional environmental benefits were determined using yes or no which relate to 5 points or zero points. A criterion 5 is broken into two parts: criteria 5a and criteria 5b. A criterion 5a represents additional environmental benefits and a criterion 5b represents potential toxic effects. For additional environmental benefit media may provide benefit besides Nitrate and Orthophosphate reduction such as heavy metal or TSS reduction. Criteria 5b, potential toxic effect allows for potential media to be eliminated because of potential toxic effects to the environment such as addition of heavy metals or other toxic materials. If potential media receive a qualitative yes rating for criteria 5b, they are eliminated from quantitative media selection, therefore newspaper is not present in Table 3. Yes or no decision making criteria are used for both criteria 5a and 5b. Table 3 shows the quantitative analysis of the media and the overall numerical scores for each media. The average of relevance was considered to be the score of criteria one which was then averaged with the rest of the criteria to produce an overall score. The bolded overall scores indicate media that was evaluated in the batch test.

Tables 1 and 2 have a differing numbers of media. Table 1 has 32 media and Table 2 has 29 media. The explanation for the difference in media between Tables 1 and 2 is some of the categories have been combined. For example planting soil from Table 1 was combined with sandy loam in Table 2. Table 2 combines all zeolite subcategories from Table 1 and wood compost/ leaf mulch is combined with wood fiber/ woodchips.

Table 1: Sorption Media Summary for Phosphorus and Nitrogen Removal

	Sorption Media	Additional environmental benefits	References
1.	Peat	Cu, Zn, Ni, and Mo, Zn, PAHs (polyaromatic hydrocarbons)	DeBusk et al., 1997; Clark and Pitt, 1999; Clark et al., 2001; Braun-Howland, 2003; Zhou et al., 2003; Kietlinska and Renman, 2005
2.	Alfalfa		Kim et al., 2000
3.	Activated carbon	copper, iron, lead, zinc	Clark et al., 2001
4.	Carbon sand, Enretech sand, or sand		Bell et al., 1995; DeBusk et al., 1997; Clark and Pitt, 1999; Clark et al., 2001; Seelsaen et al. 2006
4a	Sandy Loam (SL), Loamy Sand (LS), and Sandy Clay Loam (SCL)		Gungor and Unlu, 2005; Hsieh and Davis,2005; Davis and Shokouhian, 2001
4b	Planting soil		Hsieh and Davis, 2003
5.	Sawdust (untreated)	Pesticide and phosphate	Kim et al., 2000; Gan et al., 2004 ; Schipper and Vojvodic-Vukovic, 2001; Robertson and Cherry, 1995; Robertson, 1999
6.	Paper, newspaper		Kim et al., 2000
7.	Lignocellulosic Materials/wheat straw		Kim et al., 2000 ; Tshabalala, 2002
8.	Tire Crumb		Lisi et al., 2004
9.	Sulfur/Limestone	TSS	DeBusk et al., 1997; Kim et al., 2000; Kim et al, 2003; Darbi et al., 2002; Zhang, 2002 ; Sengupta and Ergas, 2006
9a	Crushed oyster and sulfur		Sengupta and Ergas, 2006.
10.	Wood fiber/wood chips	Polynuclear aromatic hydrocarbons	Kim et al, 2000; Boving and Zhang, 2002; Kim et al, 2003; Savage and Tyrrel, 2005; Ray et al., 2006 ; Seelsaen et al. 2006
11.	Wood compost/ leaf mulch compost	Heavy metal	Richman, 1997; Clark and Pitt, 1999; Kim et al., 2000; Kim et al, 2003; Clark et al., 2001; Savage and Tyrrel, 2005; Seelsaen et al. 2006 ; Davis and Shokouhian, 2001; Jokela et al., 2002
12.	Zeolites	Benzene, sulfate , chromate	Clark and Pitt, 1999; Li, 2003; Seelsaen et al. 2006
13.	Cotton waste		Rocca et al., 2005
14.	Perlite		Redco II, 2007
15.	Clay	phosphates, thiocyanates, cadmium, lead, nickel	Harris et al., 1996 ; Gálvez et al., 2003 ; Lazaridis, 2003
15a	Zeolites+clay	phosphates,	Gisvold, B. et al., 2000
15b	Zeolites+bark	phosphates,	Bolan et al., 2004
16.	Shale and masonry sand		Forbes et al., 2005
17.	Waste foundry sand	TCE, alachlor, and Metolachlor, Zinc	Benson, 2001
18.	Acid soils (spodosols)		USDA, 2007
19.	Opoka	Zinc	Braun-Howland, 2003
20.	Wollastonite		DeBusk et al., 1997; Hedström, 2006
21.	Iron sulfide (pyrite)		Tesoriero et al., 2000 ; Baeseman et al., 2006
22.	Limerock		DeBusk et al., 1997
23.	Polyurethane porous media		Han et al., 2001
24.	Clinoptilolite		Hedström, 2006
25.	Blast furnace slag		Hedström, 2006
26.	Emulsified edible oil substrate		Lieberman et al., 2005
27.	Allophane		AEC, 2007
28.	Chitin		AEC, 2007
29.	Pumice		AEC, 2007
30.	Bentonite		AEC, 2007
31.	Oversize “pulverized brick		Savage and Tyrrel, 2005 ; Jokela et al., 2002
32.	Polystyrene packaging		Savage and Tyrrel, 2005

Table 2: Qualitative Sorption Media Assessment

No.	Sorption Media	Criteria 1		Criteria 2	Criteria 3	Criteria 4	Criteria 5	
		1a	1b				5a	5b
1.	Florida Peat	E	E	L	L	Y	Y	N
2.	Alfalfa	G	G	H	H	N	Y	N
3.	Activated carbon	E	P	H	H	N	Y	N
4.	Carbon sand, Enretech sand, or sand	E	P	H	H	N	Y	N
4a	Sandy Loam (SL), Loamy Sand (LS), and Sandy Clay Loam (SCL), Planting soil	E	E	M	L	Y	Y	N
5.	Sawdust (untreated wood)	G	E	M	L	Y	Y	N
6.	Paper, newspaper	G	E	M	L	Y	Y	Y
7.	Lignocellulosic Materials/wheat straw	G	G	H	H	N	Y	N
8.	Tire Crumb /electron donor	VG	E	M	M	Y	Y	N
9.	Limestone/ electron donor	F	E	H	L	Y	Y	N
9a	Crushed oyster/electronic donor	F	E	H	L	Y	Y	N
10.	Wood fiber/wood chips/compost	G	VG	H	L	Y	Y	N
11.	Zeolites	VG	G	H	H	N	Y	N
12.	Cotton waste	F	P	M	H	N	Y	N
13.	Perlite	VG	P	H	H	N	Y	N
14.	Shale and masonry sand	P	P	H	H	N	Y	N
15.	Waste foundry sand	P	P	H	M	N	Y	N
16.	Opoka	F	G	H	H	N	N	N
17.	Wollastonite	E	P	M	H	N	Y	N
18.	Iron sulfide (pyrite)	VG	G	H	H	N	N	N
19.	Limerock	P	VG	H	L	Y	N	N
20.	Polyurethane porous media	P	P	H	H	N	N	N
21.	Clinoptilolite	VG	P	M	H	N	Y	N
22.	Blast furnace slag	G	P	H	M	N	N	N
23.	Emulsified edible oil substrate	P	P	L	H	N	N	N
24.	Allophane	P	P	L	H	N	N	N
25.	Chitin	VG	P	M	H	N	N	N
26.	Pumice	P	P	H	H	N	N	N
27.	Bentonite	E	G	L	H	N	Y	N
28.	Oversize “pulverized brick	VG	F	H	M	Y	Y	N
29.	Polystyrene packaging	P	P	H	H	Y	N	N

Criteria matrix: 1. relevance, 2. permeability, 3. cost, 4. availability in Florida, 5a. additional environmental benefits ,5b. potential toxic effect

1a. phosphorous (unsaturated and saturated)

1b. Nitrogen saturated

Criteria 1: E (excellent), VG (very good), G (good), F (Fair), P (Poor)
Criteria 2 and 3: Low, Medium, High / Criteria 4 and 5a,b: Yes or No

Table 3: Quantitative Sorption Media Assessment

No.	Sorption Media	Criteria 1		Criteria 2	Criteria 3	Criteria 4	Criteria 5	Overall*
		1a	1b					
1.	Florida Peat	5	5	5	5	5	5	**5**
2.	Alfalfa	3	3	1	1	0	5	2
3.	Activated carbon	5	1	1	1	0	5	2
4.	Carbon sand, Enretech sand, or sand	5	1	1	1	0	5	2
4a	Sandy Loam (SL), Loamy Sand (LS), and Sandy Clay Loam (SCL), Planting soil	5	5	3	5	5	5	**4.6**
5.	Sawdust (untreated wood)	3	5	3	5	5	5	**4.4**
6.	Lignocellulosic Materials/wheat straw	3	3	1	1	0	5	2
7.	Tire Crumb /electron donor	4	5	3	3	5	5	**4.1**
8.	Limestone/ electronic donor	2	5	1	5	5	5	**4.88**
8a	Crushed oyster/electronic donor	2	5	1	5	5	5	**4.88**
9.	Wood fiber/wood chips/compost	3	4	1	5	5	5	**4.88**
10.	Zeolites	4	3	1	1	0	5	2.1
11.	Cotton waste	2	1	3	1	0	5	2.1
12.	Perlite	4	1	1	1	0	5	1.9
13.	Shale and masonry sand	1	1	1	1	0	5	1.6
14.	Waste foundry sand	1	1	1	3	0	5	2
15.	Opoka	2	3	1	1	0	0	0.9
16.	Wollastonite	5	1	3	1	0	5	2.4
17.	Iron sulfide (pyrite)	4	3	1	1	0	0	1.1
18.	Limerock	1	4	1	5	5	0	2.7
19.	Polyurethane porous media	1	1	1	1	0	0	0.6
20.	Clinoptilolite	4	1	3	1	0	5	2.3
21.	Blast furnace slag	3	1	1	3	0	0	1.2
22.	Emulsified edible oil substrate	1	1	5	1	0	0	1.4
23.	Allophane	1	1	5	1	0	0	1.4
24.	Chitin	4	1	3	1	0	0	1.3
25.	Pumice	1	1	1	1	0	0	0.6
26.	Bentonite	5	3	5	1	0	5	3
27.	Oversize “pulverized brick	4	2	1	3	5	5	3.4
28.	Polystyrene packaging	1	1	1	1	5	0	1.6

Criteria matrix: 1. relevance, 2. permeability, 3. cost, 4. availability in Florida, 5. additional environmental benefits
1a. phosphorous (unsaturated and saturated)
1b. Nitrogen saturated
Quantitative evaluation (qualitative evaluation)
Criteria 1: 5 (excellent), 4 (very good), 3 (good), 2 (Fair), 1 (Poor)
Criteria 2 and 3: 1(Low), 3 (Medium), 5 (High)
Criteria 4 and 5: 5 (Yes) or 0 (No)
* Overall is calculated as weighted average based on equal weight among five criteria

The following media were selected for batch test experimentation: Florida peat, sandy loam, woodchips, crushed oyster shell, crushed limestone, tire crumb and sawdust. All of the media being considered for batch test experimentation have the ability to sorb Phosphorus; however only Florida peat, woodchips and sawdust have the ability to remove Nitrate-Nitrogen. In denitrification an electron donor is required for denitrifying bacteria to convert Nitrate to Nitrogen gas. It is understood that "Nitrate reduction requires an electron donor which maybe supplied by endogenous respiration or an external carbon source" (Tchobanoglous, 2002). Florida peat, woodchips, and sawdust function as electron donors that help facilitate denitrification. The aforementioned electron donors are to be used in conjunction with the remaining media in order to attain both Nitrogen and Phosphorus removal. Newspaper was not selected because of the potential toxic effects of ink.

Florida peat is composed of organic materials that have broken down over many years. Vegetation within an area dies and decomposes and after many years this decayed material becomes peat. Sandy loam is soil that is composed of sand, silt and clay. Sandy loam contains the greatest percentage of sand followed by silt and clay. Crushed oyster shell and limestone are crushed and sieved to desired particle size. Untreated sawdust from the cypress tree was used in this experiment. Tire crumb is granulated rubber that may created by grinding up used tires. Tire crumb as a potential media amendment is exciting because the waste stream for one industry becomes raw materials for another industry.

Past Media Investigations

Literature documenting previous media studies supports the selection of the selected seven media for batch test experimentation. In a study done by Debusk and Langston laboratory columns were used to test the effectiveness of quartz builder's sand, crushed lime rock (2.5cm nominal size), fresh organic peat soil, and wollastonite for pollutant removal of runoff. The influent water going to the filters was approximately pH neutral. The effluent from the peat columns was more acidic than other effluents from other media types. The peat effluent had a pH value of 6, which gradually rose until stopping at 6.7 pH units. The effluent pH from the lime rock columns was consistently near 7.8. The sand, peat and lime rock column removed approximately 41% of the TP (Debusk, 1997). The depressed pH observed by Debusk in the effluent of the peat-sand treated water may be elevated by crushed limestone, crushed oyster shells, or some other form of calcium carbonate as a substitute for the sand. Clark and Pitt noted the disadvantages of using sand-peat filters opposed to simple sand filters were color and turbidity increase and pH decrease. The typical decrease in pH was 1-2 pH units. The same study indicated overall particulate sediment removal efficiency for sand and peat to be 93% and 47% (Clark, 1999). Additional research indicated that under anaerobic conditions peat moss released previously sorbed Ammonia and Nitrate. The Phosphorus retention for sand and peat was found to be excellent for both aerobic and anaerobic conditions (Clark, 2001).

Within the media chosen for further experimentation, peat, woodchips and sawdust were assumed to function as electron donors and therefore any Phosphorus removal may be regarded as an added benefit. A wetland study highlighting the effect of organic carbon on Nitrogen transformations suggests peat as an excellent source of carbon for denitrifying bacteria. The source of peat for this experiment was the southern wetlands of Sweden. The study found a positive correlation between Nitrate consumption and soil organic matter content (Davidsson and Stahl, 2000). An experiment by Kim which focused on electron donor selection with respect to denitrification showed Nitrate removals for sawdust media and wood chip media to be approximately 95% (Kim, 2000). The study also analyzed columns with sulfur and columns with sulfur and limestone. The columns with limestone showed higher alkalinity values than the sulfur only columns. The sawdust and woodchips were cut and passed through a 2 mm sieve. The limestone was sieved to obtain a particle range of 0.6-1.18mm. The synthetic storm water within the experiment consisted of 2 mg/L Nitrate as N, 120 mg/L $CaCl_2$, 0.6 mg/L Na_2HPO_4 as P, and pH 7. The experiment showed higher turbidity values for the wood chip effluent compared to the sawdust effluent. A bioretention study using soil from Caroline County, Maryland and shredded hardwood bark mulch showed moderate removal for various nutrients: Phosphorus reduction of approximately 80%, TKN reduction of 65 to 75% and ammonium reduction of 60 to 80% (Davis, 2001). The nutrients in the synthetic storm water runoff were 2 mg/L $NaNO_3$ as N, 4 mg/L NH_2CH_2COOH as N and 0.6 mg/L Na_2HPO_4.

Schipper and Vjvodic-Vukovic created and tested a denitrification wall composed of excavated soil and sawdust (30% v/v) from Pinus radiata. The results of the study show decreased Nitrate concentrations in the groundwater as a result of the denitrification wall (Schipper and Vjvodic-Vukovic, 2001). Nitrate concentrations entering the denitrification wall varied between 5 and 16 mg/L as N and Nitrate concentrations within the denitrification wall were between 0.6-2 mg/L as N. Robertson and Cherry created and tested porous reactive media barriers that consisted of sand, silt, sawdust, peat and gravel and sand, these media barriers. Typical upgradient Nitrate concentrations ranged from 60 to 65 mg/L as N. After one year of operation the reactive media barriers achieved between 72% and 97% Nitrate removal efficiency (Robertson and Cherry, 1995). Within the porous reactive media barrier crushed limestone was added to buffer acidity generated by effluent oxidation. Another study by Robertson showed 89% to 96% reduction in ammonium and Nitrate within an infiltration bed comprised of sand in the unsaturated zone and sawdust from Canadian course hardwood in the saturated zone (Robertson, 1999). The combined inorganic Nitrogen influent of NH_4^+ and NO_3^- was approximately 24.8 mg/L as N. Darbi suggested that limestone of grain size 2.38-4.76mm was added to a sulfur/limestone autotrophic denitrification (SLAD) system to maintain pH (Darbi, 2002). Sengupta's experiment shows that sulfur/crushed oyster shell have higher denitrification rates, effluent pH and alkalinity compared to sulfur/limestone and sulfur/marble chips (Sengupta and Ergas, 2006). Average Nitrate removal for the sulfur/crushed oyster shell and sulfur/limestone were 80% and 53%. Lisi showed that tire crumb amended putting green reduced Nitrate from leachate samples by approximately 60% as compared to the USGA standard putting green profile (Lisi, 2004). The mechanism of Nitrate removal via tire crumb was not specified in this experiment.

CHAPTER THREE: EXPERIMENTAL SETUP

Batch Test Approach

The purpose of batch test experimentation is to find filter media that may reduce nutrients that are found in stormwater runoff. Filter media are selected based on their ability to remove Orthophosphate (OP) and Ammonia Nitrogen. Since denitrification is not possible within batch test experimentation removing OP rather than Nitrate is the main focus. Sorption is the mechanism by which OP and Total Phosphorus are removed from stormwater. To meet Phosphorus reduction requirements potential media must perform favorably in batch test experimentation.

As previously stated in Chapter 2 an electron donor is required to facilitate denitrification. The potential electron donors'; peat, woodchips and sawdust may contribute Ammonia. Batch test experimentation may allow for the selection of media with the greatest OP sorption and lowest Ammonia contribution.

Seven different media are selected for the batch test experimentation based on the selection criteria found in the media selection section of this report and past media investigation found in Chapter 2. Batch test experimentation is necessary to find the optimal media mix that may be used for column test experimentation. Potential filter media mixes are analyzed and compared using results from 1, 6, 12, 24 and 48 hour batch tests. Batch test time steps 1, 6, 12, 24 and 48 hours were determined through trial and error to find equilibrium for batch test media. Determination of equilibrium is necessary because of continuous uptake and release of nutrients within batch test filter media. Proper determination of media equilibrium may allow for the quantification of Ammonia release and OP sorption of media. Analysis of batch test filter media begins with relatively simple filter media mixes however complexity of media blends increases as media amendments are added to the simple filter media. The batch test experimentation tests 11 initial mixes that consist of the seven selected media. The 11 recipes are ranked based on the criteria used in Chapter 2. The top two recipes with the greatest removal potential with respect to Orthophosphate (OP), Total Phosphorus (TP), Nitrate and Ammonia are selected for column test experimentation. The results of the batch test indicate the marginal effects of each potential media with respect to Total Phosphorus (TP), Orthophosphate (OP), Ammonia and Nitrate in an aerobic environment. Table 4 shows a list of the 11 initial media mixes and the marginal effect resulting from addition of media.

Table 4: 11 Initial Batch Test Recipes

Test case	Recipe	Marginal effect
Control case	100% fine sand/coarse silt	-
1	50% Sand/Silt 50% Sawdust	to test the marginal effect of adding Sawdust
2	50% Sand/Silt 50% Mulch (Wood Chips)	to test the marginal effect of adding Wood Chips
3	50% Sand/Silt 25% Sawdust or Wood Chips (pick the one which has a better performance in tests 1 and 2) 25% Florida Peat	to test the marginal effect of adding Peat
4	50% Sand/Silt 25% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 25% Tire Crumb	to test the marginal effect of adding Tire Crumb
5	50% Sand/Silt 25% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 15% Tire Crumb 10% Limestone	to test the marginal effect of adding Limestone with Tire Crumb
6	50% Sand/Silt 25% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 15% Tire Crumb 10% Oyster	to test the marginal effect of adding Oyster with Tire Crumb
7	50% Sand/Silt 25% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 15% Florida Peat 10% Oyster	to test the marginal effect of adding Oyster with Florida Peat
8	50% Sand/Silt 25% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 15% Florida Peat 10% Limestone	to test the marginal effect of adding Limestone with Florida Peat
9	50% Sand/Silt 15% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 15% Florida Peat 10% Limestone 10% Tire crumb	to test the marginal effect of adding Limestone with Florida Peat/Tire Crumb
10	50% Sand/Silt 15% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 15% Florida Peat 10% Oyster 10% Tire crumb	to test the marginal effect of adding Oyster with Florida Peat/Tire Crumb
11	50% Sand/Silt 10% Sawdust or Wood Chips (pick the one which is better performed in tests 1 and 2) 10% Florida Peat 10% Oyster 10% Tire crumb 10% Limestone	to test the marginal effect of adding Limestone with Oyster, Florida Peat/Tire Crumb

Batch Test Experimental Setup

Table 5 shows the procedure for batch test experimentation and Table 6 shows the methods for analyzing the pollutants of concern. Table 6 shows the methodology of testing, specific test used and applicable test range for the parameters of concern. Nutrient concentrations within pond water may be highly variable therefore it is advantageous to use a test that is capable of analyzing both high and low nutrient concentrations. The specific HACH tests shown in Table 6 are utilized because of their ability to accurately detect relatively low concentrations of nutrients. The HACH tests may accurately quantify low nutrient concentrations within pond water. If pond water contains nutrient levels greater than the range of the HACH test the sample may be diluted with DI water to stay within the effective range of the test.

Table 5: Batch Test Procedure

Step	Procedure
1	The pond water samples were collected from a detention pond adjacent to the UCF police station
2	250 ml of sample was measured out and poured into a 500ml Erlenmeyer flask
3	Media blends each weighing a total of 30 grams were weighed out and added to the 250 ml sample
4	The 500ml Erlenmeyer flask which now contains water sample and media blend are now put on a shaker plate that is rotating at 125 revolutions per minute
5	The samples are taken off of the shaker plate at times 1hr, 6hr, 12hr, 24hr and 48 hr
6	The samples are then filtered using a 4.5μm glass filter
7	The filtered samples were then tested for Orthophosphate (OP), Total Phosphorus (TP), Nitrates and Ammonia Nitrogen using Methods found in Table 6

Table 6: Methods for Batch Test Experimentation

Parameter of Concern	Methodology of Test	Specific Test	Test Range
Phosphorus, Total	Acid persulfate digestion method	Hach Method 8190	0.02-2.50 mg/L PO_4^{3-}
Phosphorus, Reactive (Orthophosphate)	PhosVer 3 (Ascorbic Acid) Method	Hach Method 8048	0.02-2.50 mg/L PO_4^{3-}
Nitrogen, Nitrate + Nitrite	Cadmium Reduction Method	Hach Method 8192	0.01-0.50 mg/L NO_3^--N
Nitrogen, Nitrite	Diazotization Method	Hach Method 8507	0.002-0.300 mg/L NO_2^--N
Nitrogen, Ammonia	Salicylate Method	Hach Method 8155	0.01-0.50 mg/L NH_3-N
Nitrogen, Total	Persulfate digestion method	Hach Method 10071	0.5-25.0 mg/L N

Material Characterization

Materials characterization is done on the control, media mix 1 and media mix 2. ASTM D-421-85 Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants is used. The surface area analyses for the control and media are performed by the independent lab Quantachrome Instruments incorporated. The surface area for the media mixes is determined using an average of the recipes constituents. Bulk density and voids in soil and mixed media are measured using ASTM C29/C29M-07. ASTM D-854-92 Standard Test Method for Specific Gravity of Soils is applied for the determination of the specific gravity of control soils and media mixes that pass the 4.75-mm (No. 4) sieve.

The coefficient of permeability is found using the falling head test method. The preparation of the soil specimen follows the same procedure as the ASTM Standard D 2434-68 for the constant head method. The equipment set up follows the schematic in Figure 3. After the specimen saturation, any air bubbles within the tubing are removed. The time for the water to flow through the columns using two selected heads, h_1 to h_2, is measured. Several trials are run and averaged. The permeability is converted to a test temperature of water at 20ºC.

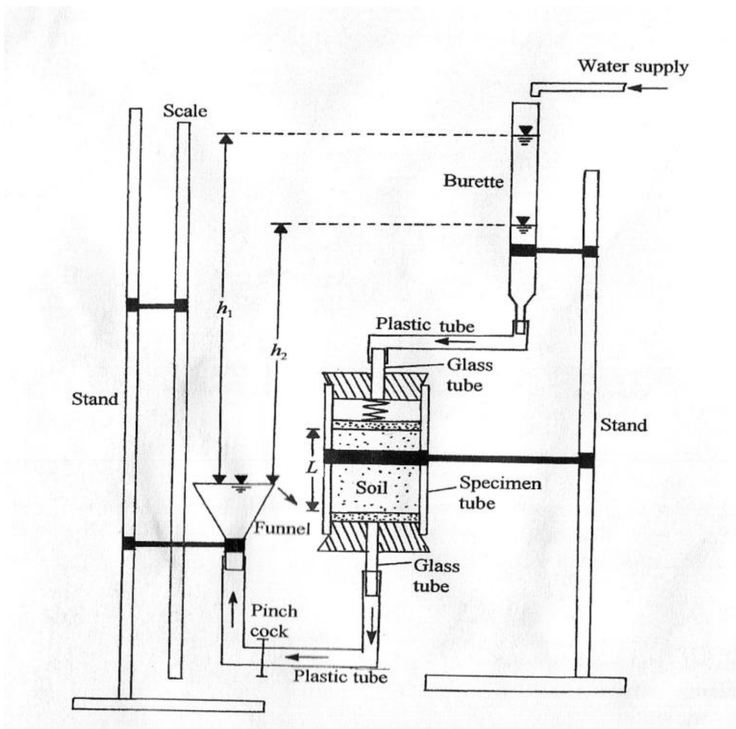

Figure 3: Schematic for the falling head permeability test (Das, 2002)

Column Test Approach

The laboratory column tests function as a model for a dry detention pond. The dry detention laboratory columns are created to model actual subsurface conditions in a controlled environment. The first column simulates a path through the unsaturated aerobic semi-dry vadose zone and the second column simulates a saturated anaerobic environment. In the natural environment runoff first percolates through the unsaturated semi dry vadose zone and then enters the saturated anaerobic environment. The experiment contains three pairs of columns: control, media mix 1 and media mix 2. To model actual subsurface conditions each column pair consists of an unsaturated column followed in series by a saturated column. The unsaturated column in each column pair contains natural soil from the Hunters Trace pond. The second column within each column pair contains either natural soil from Hunters Trace, media mix 1 or media mix 2. Augmented stormwater first enters the unsaturated column and is allowed to percolate to the bottom of the unsaturated column. To mimic subsurface conditions the water is pumped into the saturated column. The Hunters Trace pond is located in Ocala, Florida at coordinates 29°11'49.42"N, 82° 3'52.83"W. The Hunters Trace Pond is located within 1 mile of Silver River State Park. Figure 4 shows a map of Hunters Trace Pond adjacent to Silver River State Park. In Figure 4 Hunters Trace Pond is shown using a blue marker.

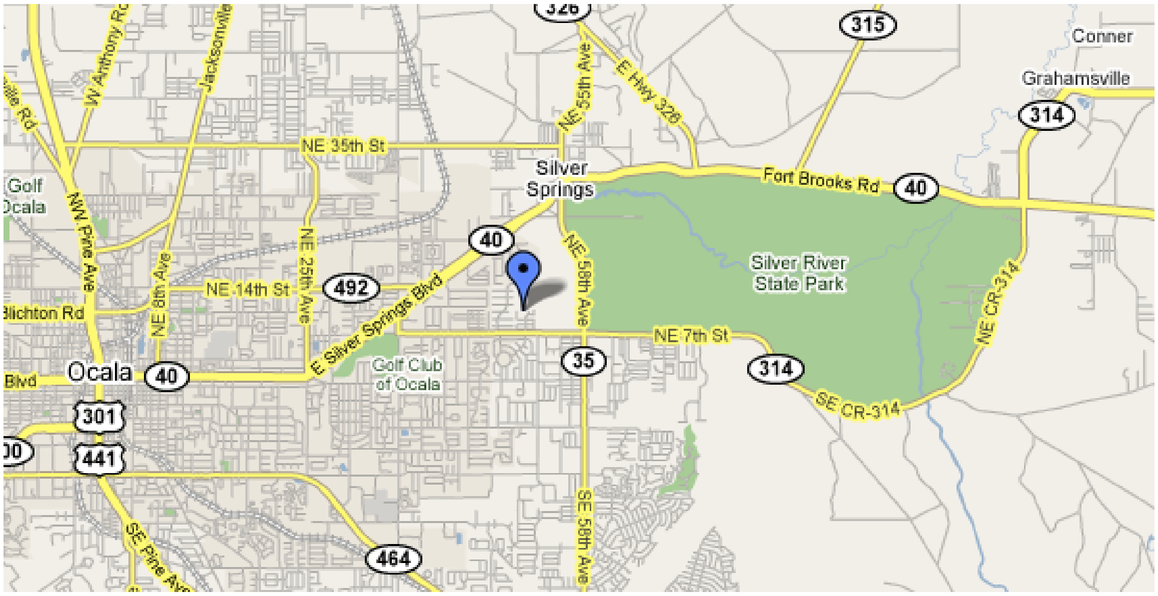

Figure 4: Hunters Trace Pond

The nutrient removal performance of the natural soil may be quantified by analyzing the control case. Media mix 1 is located in the saturated column of pair 2 and media mix 2 is located in the saturated column of pair 3. Media mixes 1 and 2 simulate a saturated anaerobic environment where each media mix is added to reduce nutrients. Pond water from the pond adjacent to the UCF engineering building is augmented with Nitrate Nitrogen and Orthophosphate to determine the nutrient removal potential of the selected media. Different concentrations of Nitrate Nitrogen are added to the columns to measure the Nitrogen removal potential of media mixes 1 and 2. Various concentrations of Orthophosphate are added to measure Phosphorus sorption potential. Comparing the results of the column tests may be used to quantify the effectiveness of filter media mixes 1 and 2 for stormwater nutrient reduction.

Column Test Experimental Setup

Three pairs of Plexiglas columns are prepared in the laboratory at UCF to perform the experiment. The Plexiglas columns have a length and diameter of 6 feet and 6 inches (outside diameter), 5.8 inches (inside diameter). The columns are commercially purchased from an outside vendor. All six columns are secured with fabric straps onto a wooden frame that was attached to a steel rack within a UCF laboratory. Each of the six columns contains 3 sampling ports that may be used to take samples at different depths within the column. All joints and sampling ports are sealed using Rectorsell 5 and Plumbers putty. The top and bottom of each column may be removed via a removable screw cap. In each column holes are drilled in the removable screw caps to allow for tubing necessary for simulated stormwater runoff and ground water flow. Small plastic mesh is placed in the bottom of each column to prevent clogging. Approximately 3 inches of large gravel is placed atop the small plastic mesh to decrease clogging and loss of fine particles. Shown in Figure 5 is a laboratory picture of the columns used in column test experimentation. In Figure 6 the general column test configuration for a dry detention pond is shown.

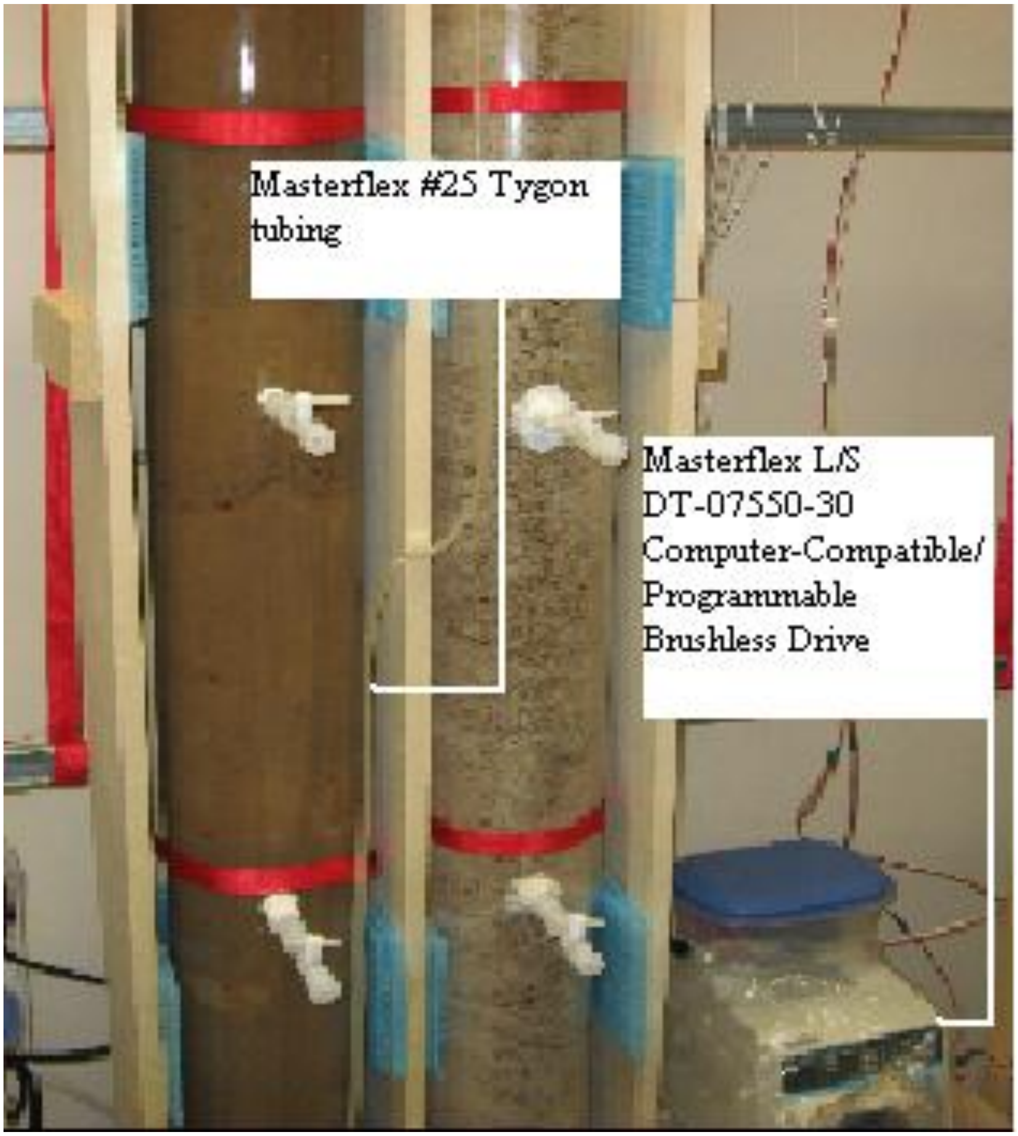

Figure 5: Laboratory Picture of Column Test Experimentation

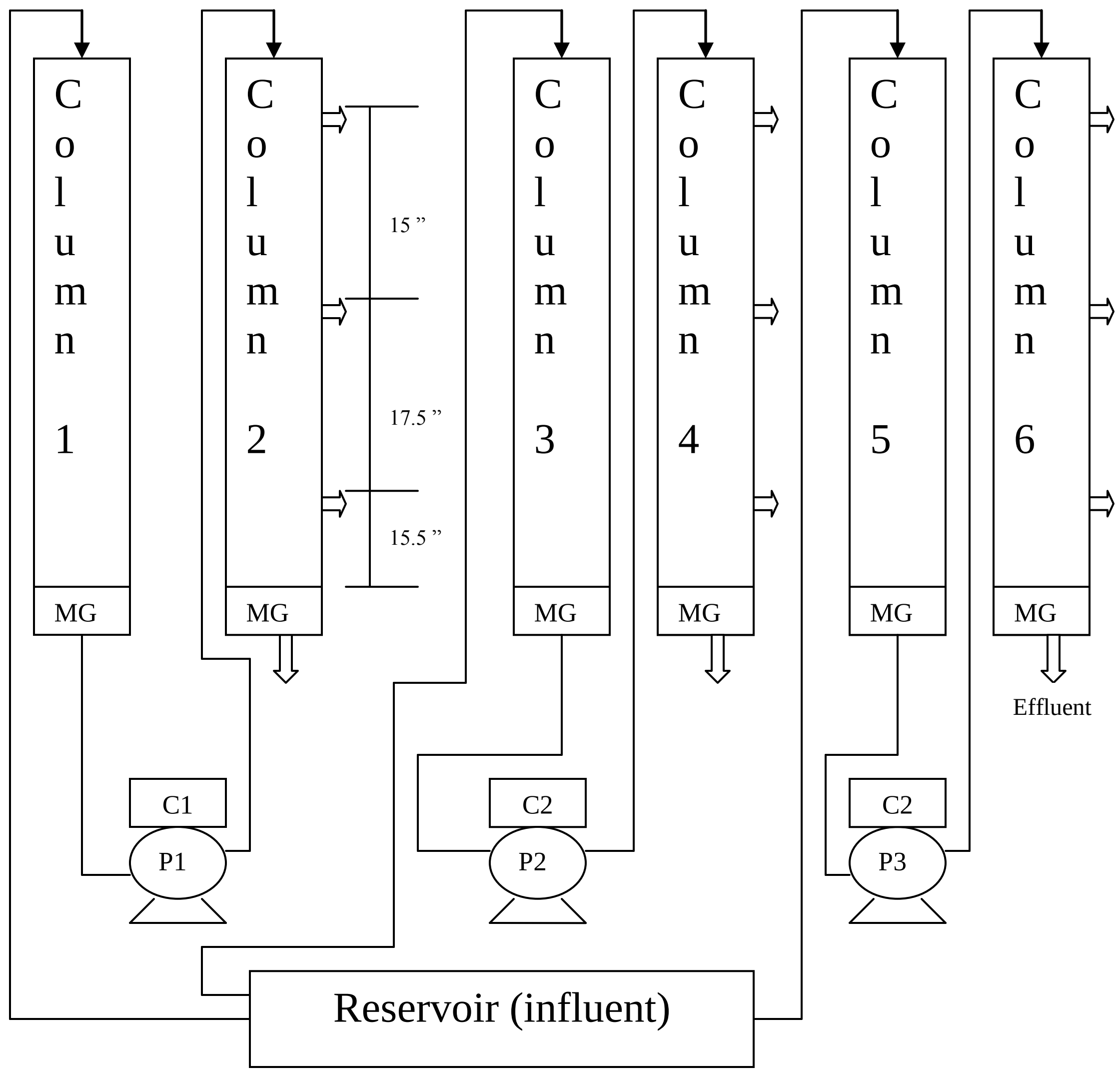

Figure 6:Column Test Configuration to simulate Dry Detention pond
MG- Small Mesh and 3” Large Gravel; P1- Peristaltic Pump 1; P2- Peristaltic Pump 2; P3- Peristaltic Pump 3; C1-Controller 1; C2- Controller 2; C3- Controller 3

All columns are filled with 48 inches of control soil or stormwater pollution control media. The position of the soil and media is shown in Figure 6. Starting slightly below port 1 there are

15” of soil or media between the top of media and the 2nd port. There are 17.5” of fill between ports 2 and 3 and another 15.5” of media or soil between ports 3 and the large gravel. Columns 1 and 2 are filled with 48 inches of natural soil from the Hunters Trace pond located in Ocala, Florida. Columns 1 and 2 are considered to be the control case. The second pair of columns consists of columns 3 and 4. Column 3 contains 48 inches of natural soil from the Hunters Trace pond and column 4 contains 48 inches of media mix 1. Columns 5 and 6 comprise the third pair of columns where column 5 contains 48 inches of natural soil from Hunters Trace pond and column 6 contains 48 inches of media mix 2. Soil collected from the hunters trace pond was sun dried for approximately 4 days to dry the soil prior to column soil compaction. Roots, insects and other organics were removed from the dry soil using a #10 sieve. Hunters Trace soil was slowly poured into columns 1, 2, 3 and 5 and compacted using a vibratory compactor. The control columns 1,2,3, and 5 should be compacted to a density of 106 lb/ft^3 Media mixes 1 and 2 were created by weighing out necessary proportions of each media and manually mixing them together. Media mixes 1 and 2 were compacted by continually pouring and compacting media in 5 pound intervals. Compaction for media mixes 1 and 2 was accomplished using a compaction rod. Column 4 media mix 1 should be compacted to a density of 42 lb/ft^3 and column 6 media mix 2 should be compacted to a density of 44 lb/ft^3.

Water is pumped from a 25 gallon reservoir to columns one, three and five which comprise the unsaturated columns. Tygon tubing provided by Master flex size 25 was used for all pumping applications throughout column test experimentation. When water reaches the bottom of columns one, three and five the water is pumped using a peristaltic pump into each of the adjoining columns two, four and six which are the saturated columns. A controller is used in conjunction with the peristaltic pump to simulate the desired stormwater runoff. To maintain saturated conditions in the saturated columns tubing exiting the saturated columns is connected to a 1 liter plastic reservoir. The position of the plastic reservoir relative to the column height sets the water level within the saturated column. The plastic reservoir is positioned adjacent to the saturated column and is vertically slightly higher than the media in the saturated column. Neglecting head loss the water level in the plastic reservoir is the same as the water level in the saturated column. Water exits the plastic reservoir through tubing that outlet into the drain. A diagram of one complete column pair featuring the unsaturated and saturated column is shown in Figure 7. The numbers adjacent to the ports in the saturated column indicate the order of the ports. Port 4 shown in Figure 7 is not actually a port; it represents the bottom of the saturated column. "Port 4" is recognized as such because it is the 4th sampling location within the column system.

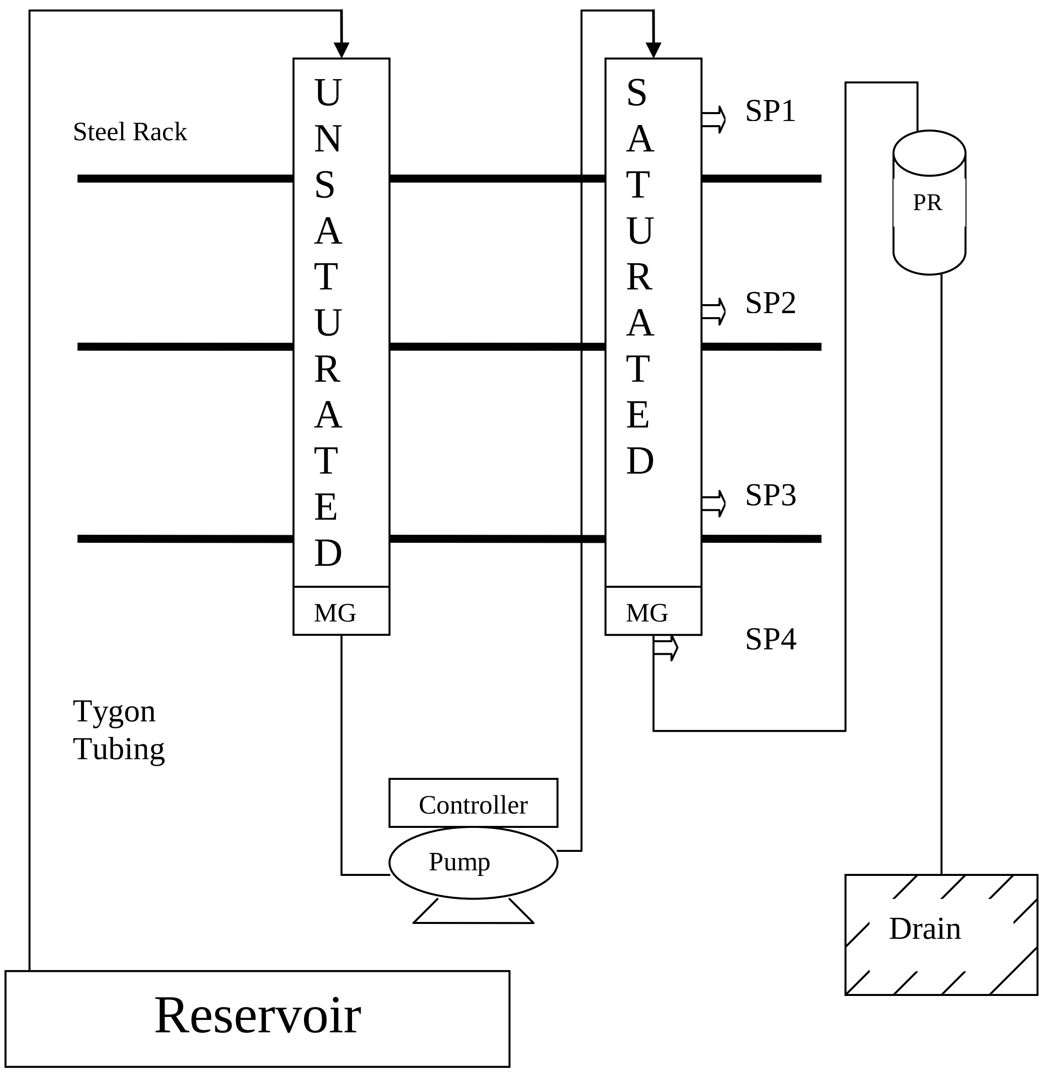

Figure 7: Complete Column Pair
SP1- Sampling Port 1; SP2- Sampling Port 2; SP3- Sampling Port 3; SP4- Sampling Port 4;
MG- Small Mesh and 3” Large Gravel; PR- Plastic Reservoir

Nutrient removal capabilities are studied with the addition of Nitrate and dissolved Phosphorus. The pond water was augmented to attain Nitrate concentrations of 0.40, 1.25 and 2.5 mg/L as Nitrate Nitrogen and Ortho Phosphorus concentrations of 0.125, 0.361 and 0.785

mg/L PO_4^- P. Augmented stormwater Nitrate and dissolved Phosphorus concentrations for column test experimentation were selected based on typical values found in the National Stormwater Quality Database (Pitt, 2004). For residential land use Nitrate extremes ranged from 0.01-10 mg/L as N or 0.04- 44.28 mg/L NO_3-N. The average for different land use categories ranged from 0.28 (1.24 mg/L as NO_3-N) mg/L as N for freeways to 0.70 (3.1 mg/L as NO_3-N) mg/L as N for open space. The median Nitrate concentration for all land uses was 0.60 (2.66 mg/L as NO_3-N) mg/L as N (Pitt, 2004). Phosphorus values ranged from 0.04 (0.123 mg/L PO_4-P) mg/L as P for mixed highways to 0.20 (0.613 mg/L PO_4-P) mg/L as P for freeways. The median value for Phosphorus considering all land use activities was 0.13 (0.40 mg/L PO_4-P) mg/L as P. Shown in Table 7 potassium Nitrate and potassium phosphate were used to create concentrated Nitrate and concentrated dissolved Phosphorus necessary for stormwater augmentation.

Table 7: Chemicals for Concentrated Nitrate and Orthophosphate
Chemicals for Concentrated Nitrate and Orthophosphate

Chemical	**Concentrated Product**
KNO_3	Nitrogen, Nitrate + Nitrite
HK_2PO_4	Phosphorus, Reactive (Orthophosphate)

To accurately quantify column performance with respect to Nitrate addition Nitrate is fixed at an approximate concentration while Total Nitrogen, Nitrate, Nitrite and Ammonia are measured. For example the initial Nitrate concentration of the pond water is measured. The pond water is spiked with concentrated Nitrate to an approximate concentration of 0.40, 1.25 and 2.5 mg/L as Nitrogen. Equation 3 below shows a generic calculation for the augmented stormwater.

$$C_{pond}V_{pond} + C_{Concentrated}V_{Concentrated} = C_{0.40,\ 1.25,\ 2.5}V_{Augmented\ Stormwater} \qquad \text{(Equation 3)}$$

Where:

C_{pond} = original nutrient concentration of pond water
V_{pond} = original volume of pond water
$C_{Concentrated}$ = concentrated spike added to pond water
$V_{Concentrated}$ = the volume of concentrated spike required to achieve approximate concentrations
$C_{0.40,\ 1.25,\ 2.5}$ = approximate concentration 0.40, 1.25 and 2.5mg/L as Nitrogen
$V_{Augmented\ Stormwater}$ = volume of augmented stormwater

The augmented stormwater is pumped through the unsaturated and saturated columns where Total Nitrogen, Nitrate, Nitrite and Ammonia are measured to quantify Nitrogen speciation and removal. Orthophosphate addition is used to determine the Phosphorus removal potential of the columns. The effects of orthophosphate addition and column performance may be quantified by fixing the orthophosphate concentration and measuring the orthophosphate and Total Phosphorus. Dissolved oxygen is measured to check for the anaerobic conditions necessary for denitrification. PH of water samples is measured during column test experimentation to verify the pond water remains from pH 6-8 and to quantify pH differences between each media and the control.

Sampling Methodology

The objective of column experimentation is to track the progress of nutrient augmented stormwater through the unsaturated and saturated columns. Proper sampling is essential to maintain and understand nutrient inputs and outputs within the column system. The porosity of each media may differ and therefore the volume of each media may be different. The retention time for each column is dependant on volume and flow rate therefore detention time is directly affected by the porosity of the media. Figure 8 shows that specific sampling locations within each column pair may have different retention times. For example port 2 media mix 1 will have a different detention time than port 2 media 2 and port 2 control because of differing porosity values. The saturated control column has the lowest porosity and therefore the highest retention time. Media 1 has the highest porosity and therefore the shortest retention time. Equation 4 below shows the equation used to calculate the retention time. Figure 8 shows the column pairs and the corresponding retention times associated with each sampling location.

$$t_d = V / Q \qquad \text{(Equation 4)}$$

Where:

t_d = detention time
$V = n \cdot \Pi \cdot d_{inside}^2 / 4$ = volume
d_{inside} = inside diameter of column
n = porosity
Q = flow rate

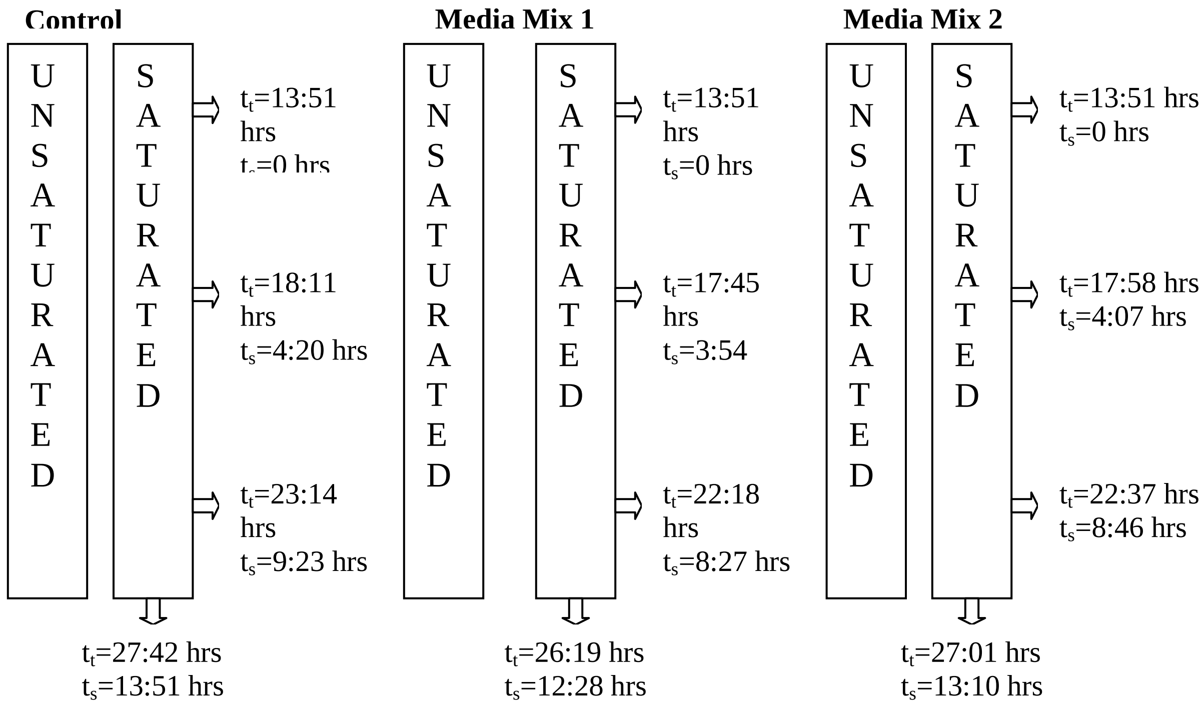

Figure 8: Retention Times for Sampling Locations
t_t=total system retention time
t_s=saturated retention time

Sampling locations with respective total system retention time (t_t) and saturated retention time (t_s) is shown in Figure 8. Total system retention time is a measure of time that the water stays within both the unsaturated and saturated columns. The saturated retention time refers to time spent in only the saturated column. The total system retention time for the reservoir is considered zero. Saturated sampling ports 1, 2, 3 and 4 are sampled to collect data necessary to track movements of nutrients throughout the saturated columns.

Sampling Procedure

The flow rate for all column pairs is constant throughout column test experimentation. The selected flow rate for column test experimentation was 10mL per minute which corresponds to 1.38 inches per hour. Typical detention pond infiltration rates range from 1-2 inches per hour (O'Reily, 2008). The flow rate was determined using typical infiltration values for detention ponds. Given a flow rate of 10mL/ minute Figure 8 shows the retention time for each sampling location within the column system. Use Figure 8 in conjunction with the following paragraph to successfully sample the column system.

Water in the reservoir is sampled at time zero to capture the influent nutrient speciation and concentration. At time 13 hours and 51 minutes (13:51) saturated port 1 is sampled. Port 1 is located approximately 3 inches above the media in the saturated zone. Analysis of port 1 shows concentration and speciation of nutrients directly following the unsaturated zone. Port 1 for all column pairs may be sampled at t=13:51. Sampling ports 2 and 3 reflect the concentration and speciation of nutrients at different intervals throughout the saturated column. Port 2 in the saturated media 1 column must be sampled at approximately 3 hours and 54 minutes t_s=3:54 after port 1 was sampled or 17 hours and 45 minutes t_t=17:45 after the reservoir was sampled. Saturated media 2/ port 2 may then be sampled at t_s=4:07 or t_t=17:58. Port 2 for the saturated control is sampled at t_s=4:20 or t_t=18:11. Ports 3 and 4 are sampled using the previously discussed methodologies. The bottoms of the saturated columns are referred to as "port 4". Port 4 may be used to evaluate nutrient removal for both the column system and the saturated column.

Table 8 located in the appendix shows the required column sampling times for each column pair and sampling location.

Table 8: Column Sampling Locations and Times

Sampling Location	Total System Retention Time (hour:min) t_t	Saturated Retention Time (hour:min) t_s
Reservoir	0	n/a
Control/ port 1	13:51	0
Media 1/ port 1	13:51	0
Media 2/ port 1	13:51	0
Control/ port 2	18:11	4:20
Media 1/ port 2	17:45	3:54
Media 2/ port 2	17:58	4:07
Control/ port 3	23:14	9:23
Media 1/ port 3	22:18	8:27
Media 2/ port 3	22:37	8:46
Control/ port 4	27:42	13:51
Media 1/ port 4	26:19	12:28
Media 2/ port 4	27:01	13:10

Dissolved oxygen is sampled by placing the DO probe inside a modified plastic cylinder. The top of the cylinder has an opening tailored for the DO probe. The bottom of the cylinder contains a male tube fitting that may be readily attached to the ports on the experimental columns. The top of the modified cylinder contains an outlet tube which flows to the drain. The DO probe is placed in the bottom of the cylinder through the top tailored opening. Duct tape is used to secure and seal the probe within the cylinder. Tubing is attached from a sampling port to the male tube fitting on the bottom of the cylinder. When the port is opened water fills the modified cylinder and completely covers the DO probe. Water is forced out of the column through the top tube opening. The DO probe should be left in the cylinder for about 30 minutes or until the DO has stabilized. pH measurements are also taken using the modified plastic cylinder, however the stabilization time for pH measurement is significantly less than DO measurement.

Shown in Tables 9 and 10 the column test procedure for stormwater augmented with Nitrate and Phosphorus. Prior to experimentation peristaltic pumps must be checked to ensure they are pumping the desired augmented stormwater flow. Columns are flushed with approximately 216 liters of pH 6-8 pond water to rid them of any accumulated nutrients. Step 3 in Table 9 is performed to confirm pH values are within an acceptable neutral range that may not be inhibitory for nitrification and denitrification. The reservoir is sampled prior to column sampling to obtain speciation and concentration of Nitrogen compounds entering the columns. Mechanical agitation is required after Nitrate and Phosphorus spiking to thoroughly mix together the pond water and the spiked solutions. Table 11 shows the methods used to determine Total Nitrogen, Nitrate, Nitrite, Ammonia, pH and DO for column test experimentation. Results of the column effluent may be compared with the reservoir influent to show nutrient removal performance of the media mixes.

Table 9: Column Test Procedure for Nitrate Addition and Testing

Step	Procedure
1	Check peristaltic pumps to confirm desired pumping rate of 10 mL per minute.
2	Flush columns with approximately 216 liters of pH 6-8 pond water
3	Before sampling confirm pond water pH is between 6 and 8.
4	Collect a 50 gallon sample of pond water from the detention pond adjacent to the UCF engineering building.
5	Find the initial Nitrate concentration of the pond water sample.
6	Spike the 50 gallon pond water sample with concentrated Nitrate solution to create augmented stormwater containing approximately 0.40, 1.25 and 2.50 mg/L Nitrate as Nitrogen.
7	Use a stirring rod to mechanically agitate the augmented stormwater.
8	Test Nitrate concentration of augmented stormwater to confirm desired Nitrate concentration.
9	Turn on peristaltic pumps.
10	Begin sampling as outlined in the sampling procedure.
11	Repeat steps 1-10 three times for each concentration.

Table 10: Column Test Procedure for Dissolved Phosphorus Addition and Testing

Step	Procedure
1	Check peristaltic pumps to confirm desired pumping rate of 10 mL per minute.
2	Flush columns with approximately 216 liters of pH 6-8 pond water
3	Before sampling confirm pond water pH is between 6 and 8.
4	Collect a 50 gallon sample of pond water from the detention pond adjacent to the UCF engineering building.
5	Find the initial Nitrate concentration of the pond water sample.
6	Spike the 50 gallon pond water sample with concentrated phosphate solution to create augmented stormwater containing approximately 0.125, 0.361 and 0.785 mg/L PO_4^- as P.
7	Use a stirring rod to mechanically agitate the augmented stormwater.
8	Test Ortho-P concentration of augmented stormwater to confirm desired Ortho-P concentration.
9	Turn on peristaltic pumps.
10	Begin sampling as outlined in the sampling procedure.
11	Repeat steps 1-10 three times for each concentration.

Table 11: Chemical Methods for Column Test

Parameter of Concern	**Methodology of Test**	**Specific Test**	**Test Range**
Phosphorus, Total	Acid persulfate digestion method	Hach Method 8190	0.02-2.50 mg/L PO_4^{3-}
Phosphorus, Reactive (Orthophosphate)	PhosVer 3 (Ascorbic Acid) Method	Hach Method 8048	0.02-2.50 mg/L PO_4^{3-}
Nitrogen, Nitrate + Nitrite	Cadmium Reduction Method	Hach Method 8192	0.01-0.50 mg/L NO_3^--N
Nitrogen, Nitrite	Diazotization Method	Hach Method 8507	0.002-0.300 mg/L NO_2^--N
Nitrogen, Ammonia	Salicylate Method	Hach Method 8155	0.01-0.50 mg/L NH_3-N
Nitrogen, Total	Persulfate digestion method	Hach Method 10071	0.5-25.0 mg/L N
PH		Fisher Scientific Accumet porTable AP61 pH meter	0-14 pH units
Dissolved Oxygen		YSI Model 58 DO Meter	

CHAPTER FOUR: RESULTS

Batch Test Results

The potential filter media blends are analyzed and compared using the results from the 1, 6, 12, 24 and 48 hour batch tests. In the batch test results below potential media mixes are analyzed and discussed based on the nutrient concentrations at time 48 hours. The analysis of batch test filter media begins with relatively simple filter media blends. The complexity of the media blends increased as media amendments are added to the simple filter media. The media amendments are made in order to test the marginal effects of various filter media. Figure 9 shows the results of the 100% sand batch test. Total P, OP and Nitrate all show negative concentrations at 48 hours.

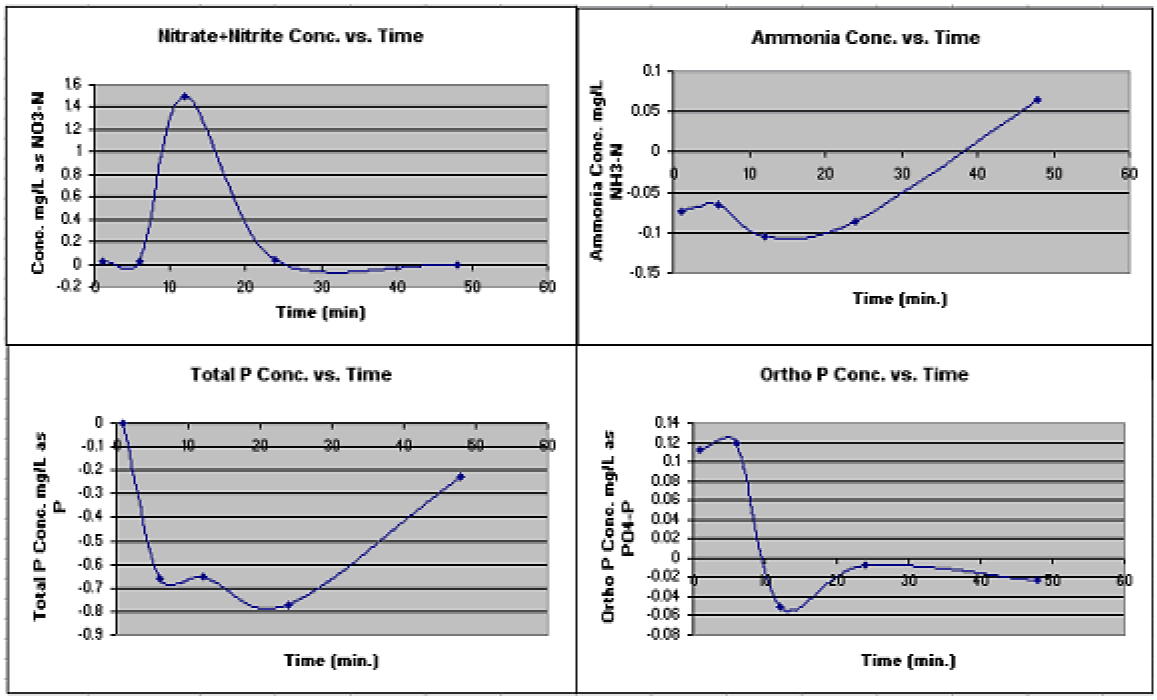

Figure 9: 100% Sand ,by weight, Control

To test the performance of tire crumb it was added to sand to create a media mix consisting of 75% sand and 25% tire crumb. Figure 10 shows decreased concentrations of Nitrates, OP and Ammonia. Despite the performance of the sand/ tire crumb blend this is not a viable filter media option because it does not contain an electron donor necessary for denitrification. An electron donor must be added in order to promote denitrification.

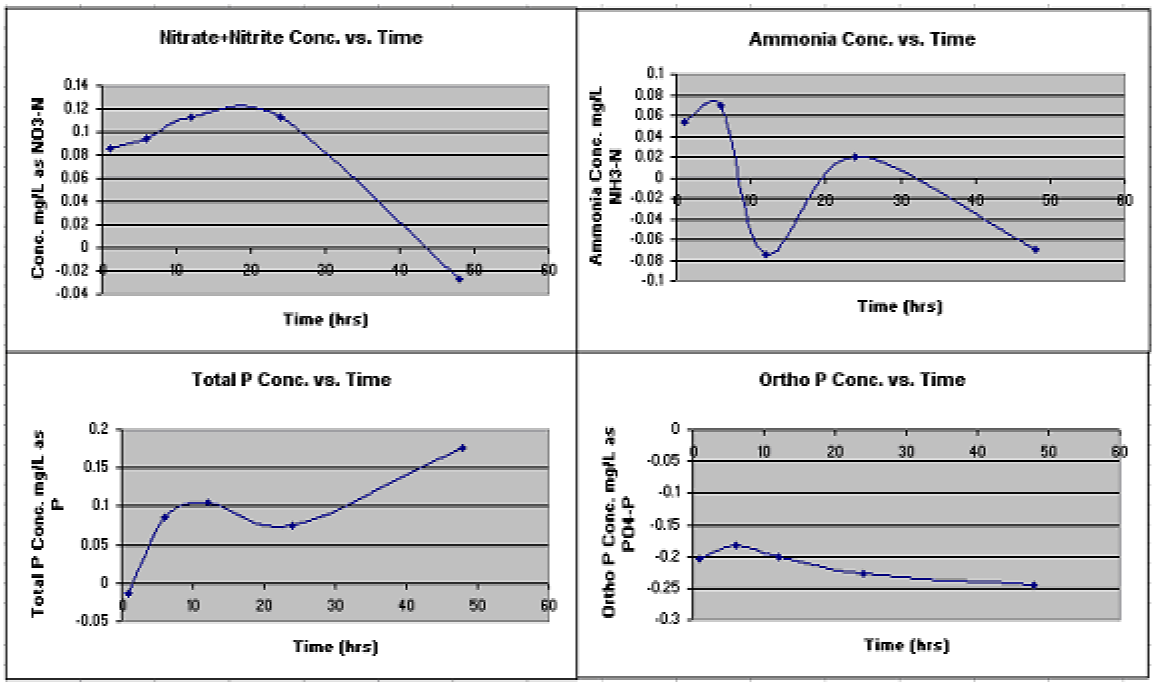

Figure 10: 75% Sand/ 25% Tire Crumb, by weight

Figure 11 shows 50% sand/ 50% sawdust media blend and Figure 12 shows 50% sand/ 50% woodchip media blend. The results of the batch tests indicate that all nutrients TP, OP, Nitrate and Ammonia are higher in the 50% sand/ 50% woodchip media than in the 50% sand/ 50% sawdust media; therefore woodchips are considered less favorable for application in stormwater filter media.

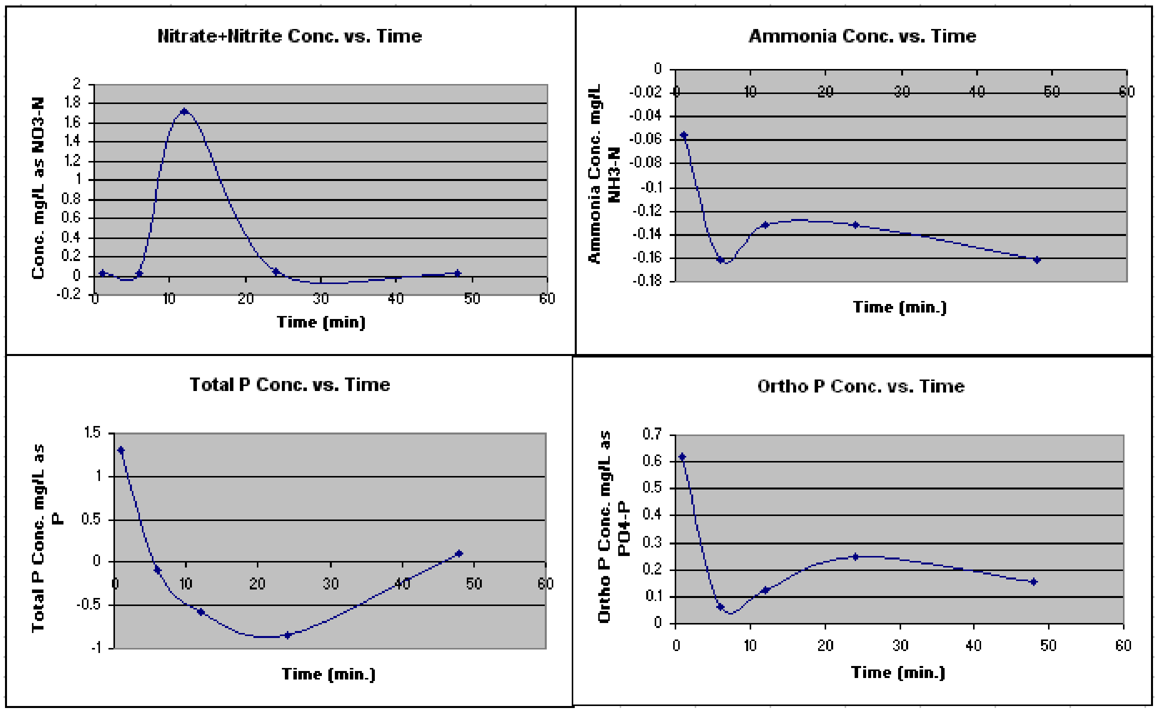

Figure 11: 50% Sand/ 50% Sawdust, by weight

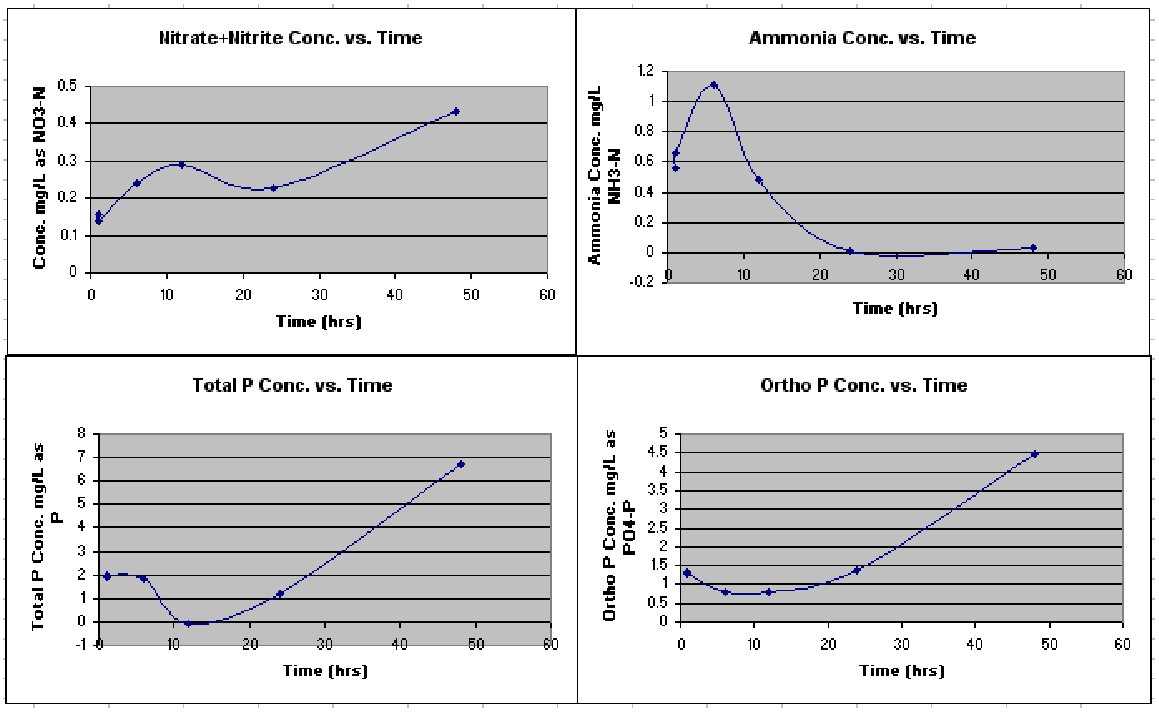

Figure 12: 50% Sand/ 50% Woodchips, by weight

To test the marginal effects of peat it was added to the sand/sawdust media mix. Figure 13 shows the results of the 50% sand, 25% sawdust and 25% peat media blend. Comparing Shown in Figures 11 and 13 the addition of peat raises the concentration of all nutrients. Increased nutrients negatively impact the performance of the media blend.

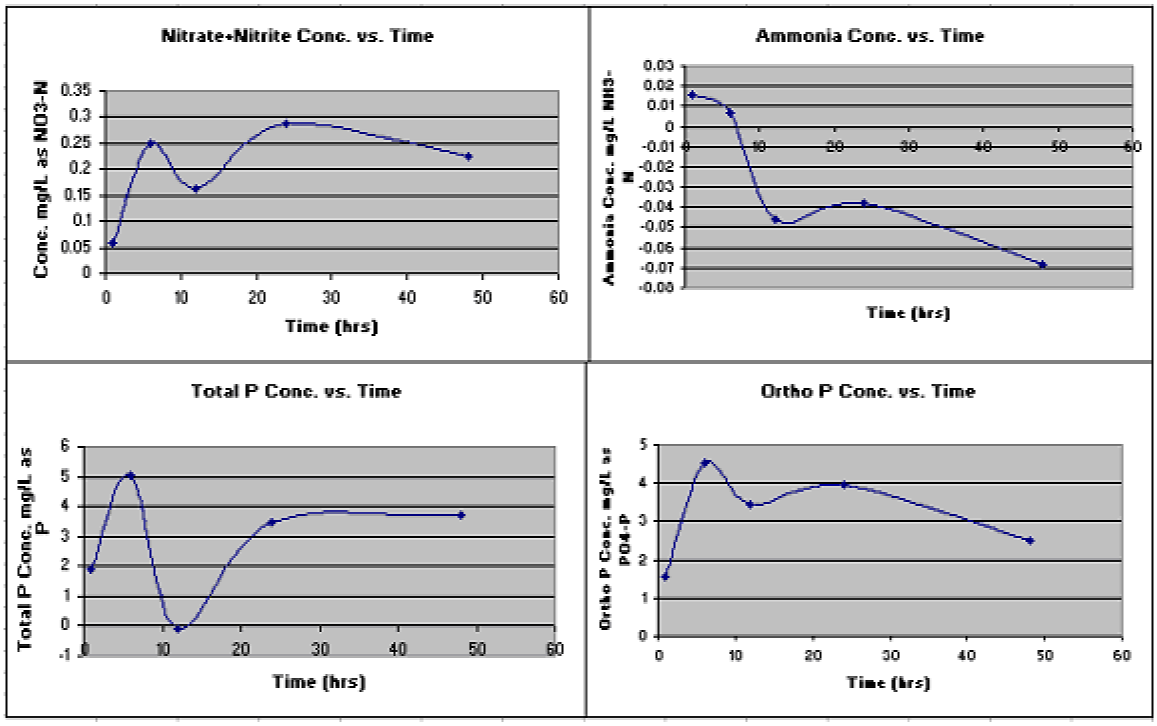

Figure 13: 50% Sand/ 25% Sawdust, 25% Peat, by weight

The sand, sawdust and peat blend shown in Figure 13 provides lower concentrations of nutrients than the sand and woodchip mix shown in Figure 12. Tire crumb is added to the sand and sawdust blend creating a recipe of 50% sand, 25% sawdust and 25% tire crumb.

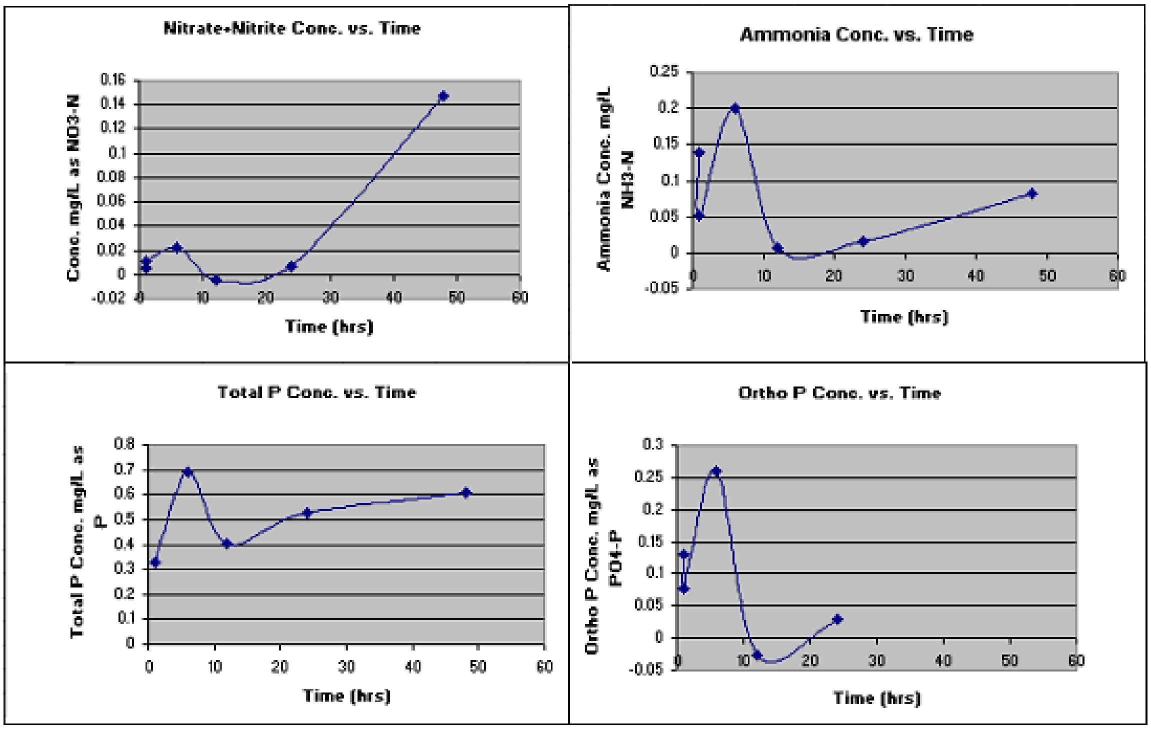

Figure 14: 50% Sand/ 25% Sawdust/ 25% Tire Crumb, by weight

The marginal effects of tire crumb addition are shown by comparing Figures 11 and 14. Based on a 48 hour retention time the marginal effects of tire crumb are increasing Total P, Nitrate and Ammonia, however decreasing OP. Since the 50% sand, 25% sawdust and 25% tire crumb media mix yielded the lowest OP concentrations different variations of this mix may be explored. Crushed oyster shell was added to the sand, sawdust and tire crumb blend to test the marginal effects of the crushed oyster shell. The results of the 50% Sand/ 25% Sawdust/ 15% Tire Crumb/ 10% Oyster media mix located in Figure 15 show that the addition of crushed oyster shell increases concentrations of Nitrate, Total P, OP, and Ammonia.

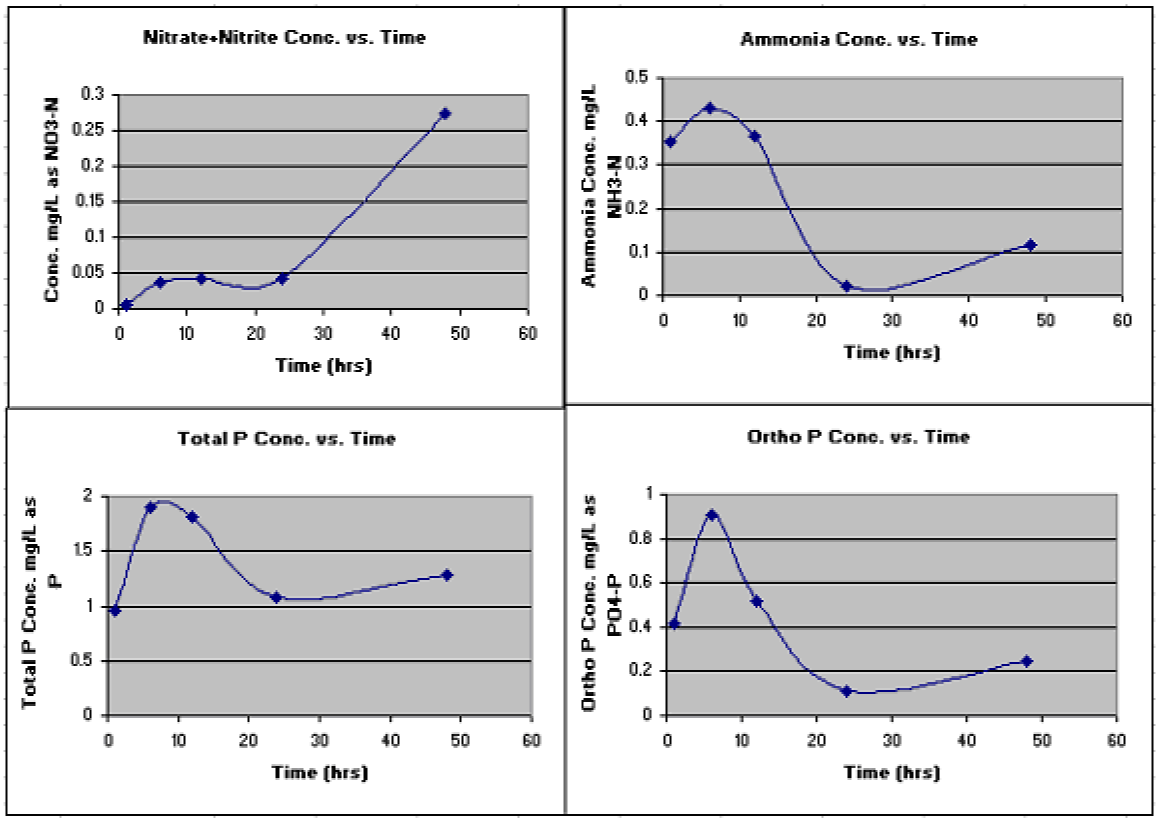

Figure 15: 50% Sand/ 25% Sawdust/ 15% Tire Crumb/ 10% Oyster, by weight

Figure 16 shows 50% sand, 25% sawdust, 15% tire crumb and 10% limestone. Comparing Figures 15 and 16 indicates that the addition of crushed oyster shell would add Ammonia and Orthophosphate while the addition of limestone would uptake both Ammonia and Orthophosphate.

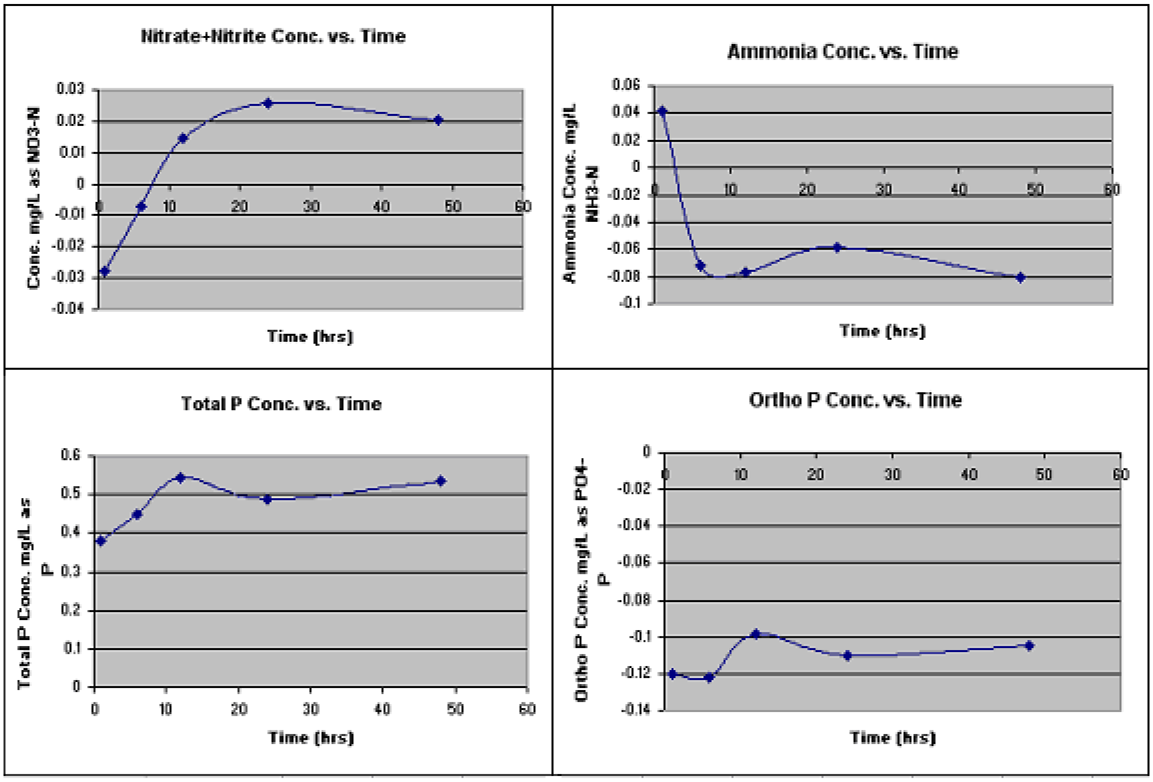

Figure 16: 50% Sand/ 25% Sawdust/ 15% Tire Crumb/10% Limestone, by weight

Previously tested filter media, crushed oyster shell and peat have been shown to negatively impact the performance of the filter media mix. Individually ineffective filter media were combined to test whether media interactions would improve the performance of the media mix. Figure 17 shows the results of a media blend consisting of 50% sand, 25% sawdust, 15% peat and 10% crushed oyster shell.

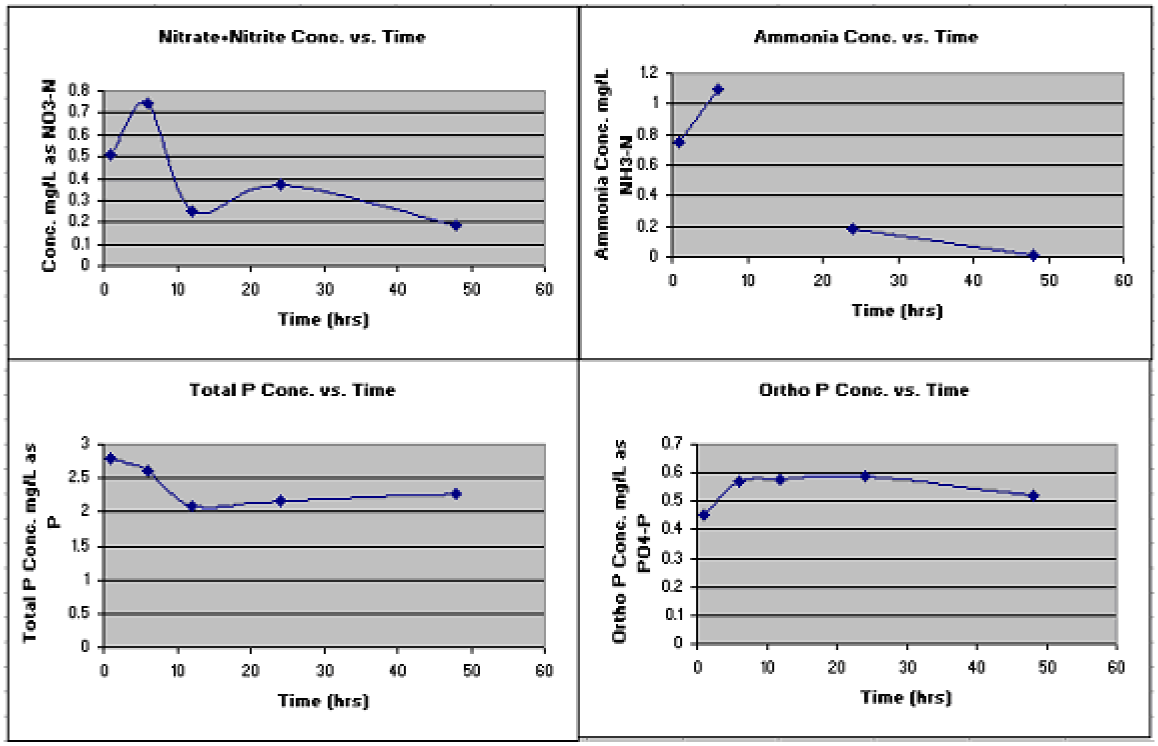

Figure 17: 50% Sand/ 25% Sawdust/ 15% Peat/ 10% Oyster, by weight

The combination of crushed oyster shell and peat did not positively contribute to the performance of the media blend. The combination of peat and crushed oyster shell show decreased performance relative to nutrient uptake as compared with previous media mixes. Comparing Figures 13 and 17 shows that the addition of crushed oyster shell into a sand, sawdust and peat media blend improved media performance with respect to Nitrate, Total Phosphorus and Orthophosphate.

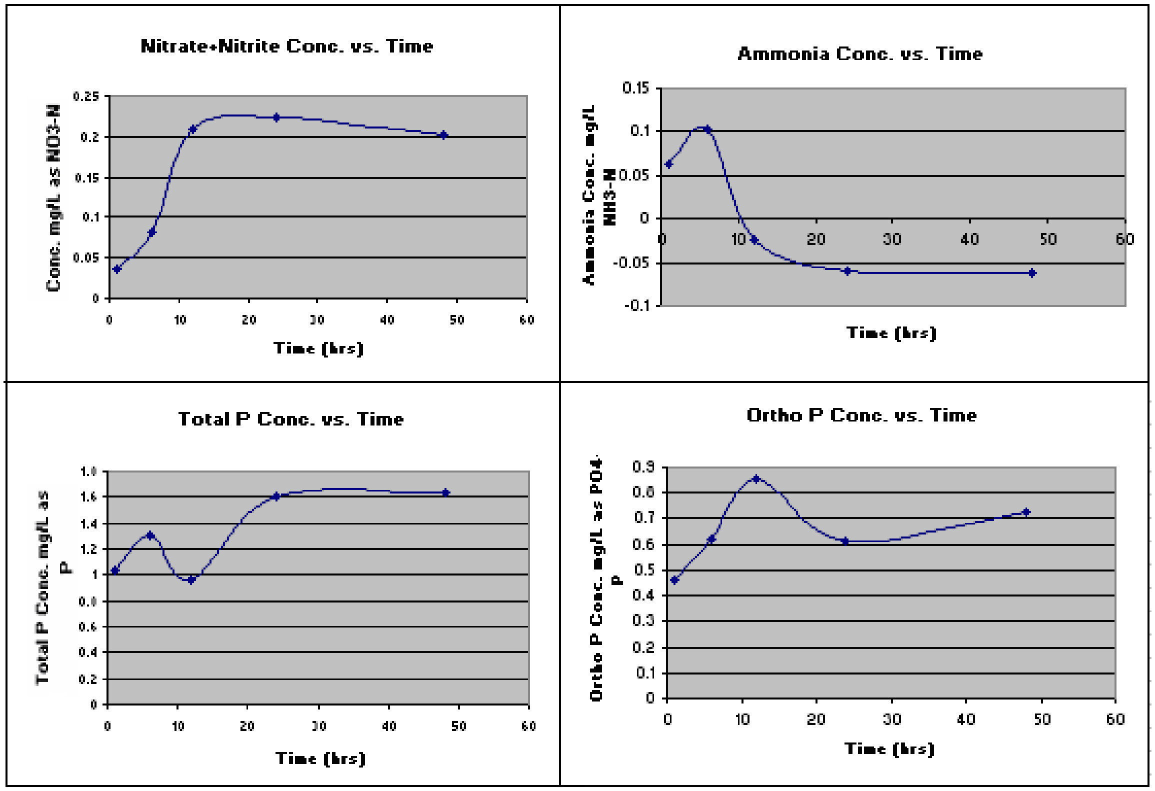

Figure 18: 50% Sand/ 25% Sawdust/ 15% Peat/ 10% Limestone, by weight

Figures 17 and 18 show limestone and crushed oyster shell compared in a media mix containing peat. Figure 17 shows a media blend consisting of 50% sand, 25% sawdust, 15% peat and 10% oyster and Figure 18 media contains 50% Sand/ 25% Sawdust/ 15% Peat/ 10% limestone. The oyster shell showed slightly lower OP concentrations yet markedly higher Ammonia and Total P concentrations. The Nitrate concentrations for both oyster and limestone mixes were nearly the same.

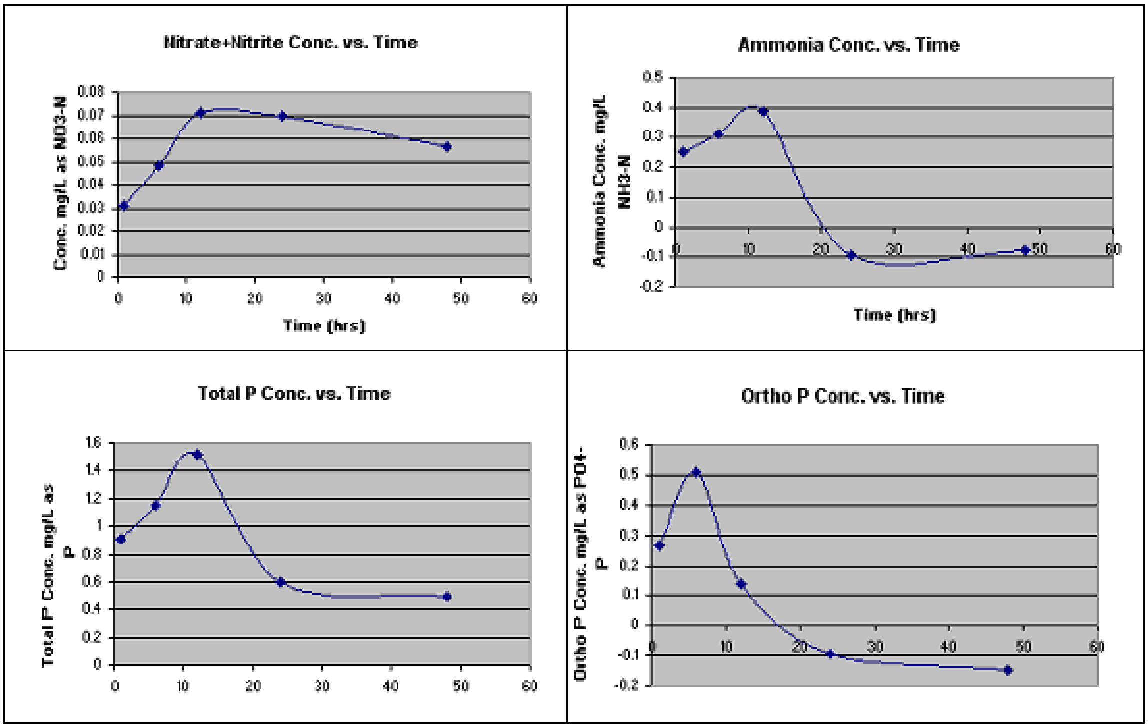

Figure 19: 50% Sand/ 10% Peat/ 10% Limestone/ 10% Sawdust/ 10% Tire Crumb/ 10% Oyster, by weight

Figure 19 shows results of batch test containing 50% sand, 10% peat, 10% limestone, 10% sawdust, 10% tire crumb and 10% crushed oyster shell. Blending these media together indicated relatively good performance with respect to the other media mixes. Previous results indicate the addition of peat and crushed oyster shells hinder batch test performance. The increased performance noticed in Figure 19 may be the result of relatively low quantities of sawdust and peat within the media blend. Many of the other batch tests have 25% electron donor (sawdust, woodchips, peat) while the media blend in Figure 19 contains only 20% electron donor. Another batch test was necessary to determine the marginal effect of decreasing the amount of sawdust in the media blend.

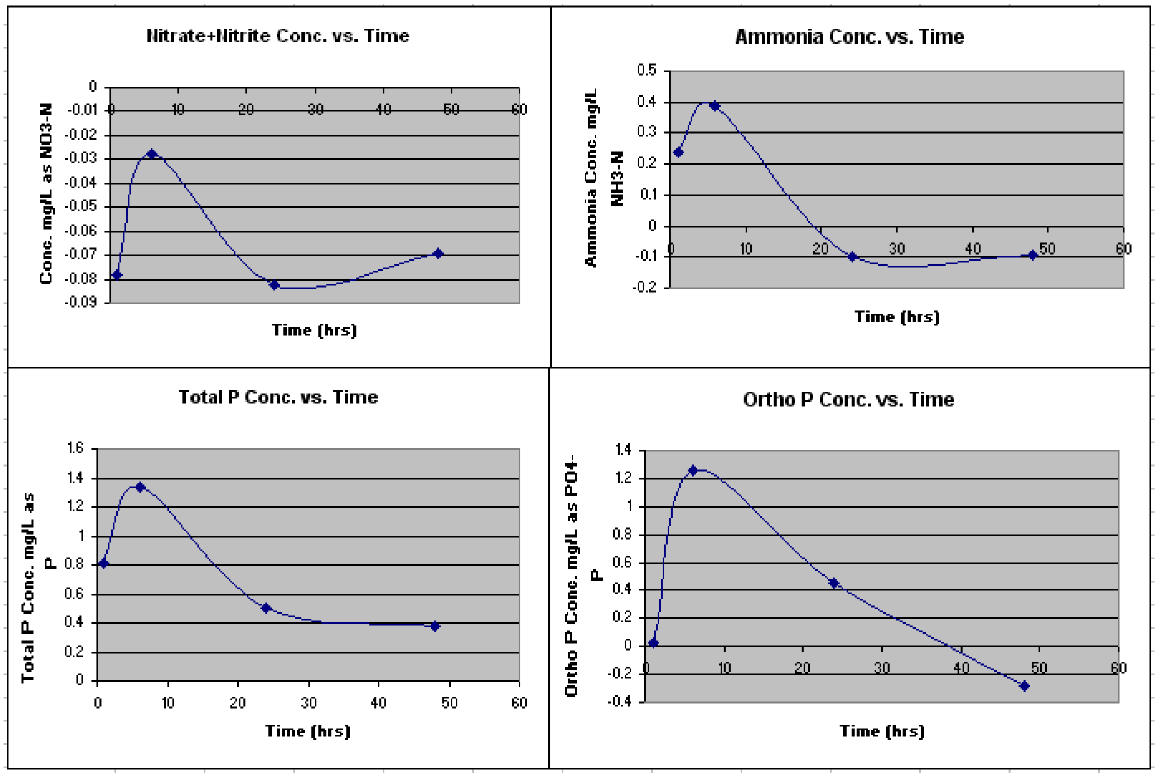

Figure 20: 50% Sand/ 30% Tire Crumb/ 20% Sawdust, by weight

Figure 20 shows the results of a batch test consisting of 50% sand, 30% tire crumb and 20% sawdust. Comparing Figures 14 and 20 shows that the media mix performance decreases as the amount of sawdust increases.

Media Selection

The results of batch test experimentation indicated that the potential electron donors Florida peat, sawdust and woodchips added considerable OP, Total P, Nitrate and Ammonia to the water sample. Out of the three electron donors sawdust added the least amount nutrients to the water. Therefore sawdust is considered the best electron donor of the materials tested and may be used in column test experimentation. Batch test results also indicated tire crumb to be highly effective in reducing OP in water samples.

The single best filter media blend with respect to Phosphorus removal and reduced Ammonia leaching may be hard to attain. Batch test experimentation shows nutrient concentrations increase as the percentage of electron donors in the media blend increase therefore it would be beneficial to quantify the amount of electron donors necessary for optimal denitrification so that optimal Phosphorus removal may also be attained. Currently it is uncertain what amount of electron donors are required for optimal denitrification. Literature indicates denitrification walls comprised of 30% v/v sawdust have had success in removing Nitrate (Schipper and Vjvodic-Vukovic,1998). Since little is known about the optimal quantity of sawdust in a media mix it is the recommendation of the UCF research team that 2 mixes with varying quantities of sawdust be used in column experimentation. The recommended two column recipes are media mix 1: 50% sand, 30% tire crumb, 20% sawdust by weight and media mix 2: 50% sand, 25% sawdust, 15% tire crumb, 10% limestone by weight.

Material Characterization

Media mix 1 and media mix 2 have now been formally defined. Media mix 1 consists of 50% sand, 30% tire crumb, 20% sawdust by weight and media mix 2 consists of 50% sand, 25% sawdust, 15% tire crumb, 10% limestone by weight. Sieve analysis and hydrometer analysis were used to determine basic soil properties of site soil (control) and blended stormwater media. Sieve analysis is ideal for soils that are mostly granular, larger than 0.075 millimeter in diameter, with some fines whereas hydrometer analysis is for determining soil size for soil fines smaller than 0.075mm. U.S. standard sieves were used for the sieve analysis (Sieve No. 60, 100, 200) and the ASTM 152H hydrometer was used for the hydrometer analysis.

Sieve Analysis was conducted to determine the particle-size distributions of the Hunters Trace, Marion County soils and the media mixes. Conrad Yelvington conducted a separate analysis for the limestone. For limestone, approximately 99% was retained on the #200 U.S. Standard Sieve while approximately 95% was retained on the #100 U.S. Standard Sieve size. Figure 21 presents the gradation curve of natural soil at the Hunter's Trace site. Figures 22 and 23 present the gradation curves for media mixes 1 and 2. The comparisons illustrate the difference in particle sizes. The natural soils are expected to be uniformly graded while the media mixes are not, which is also shown. The media mix grain size distributions will serve as quality control for future mixes and as a comparison to the existing natural parent soil materials. The effective size was determined for the control, media mix 1 and media mix 2. The effective size is used to estimate hydraulic conductivity and drainage through soil (Das 2002). The greater the effective size (D_{10}), the greater the hydraulic conductivity of the soil. Based on Figures 21-23 the effective size for the control soil, media mix 1 and media mix 2 is 0.160mm, 0.075mm and 0.080mm respectively. The control soil from Hunters Trace is poorly graded and media mix 1 and media mix 2 are well graded with respect to the control soil.

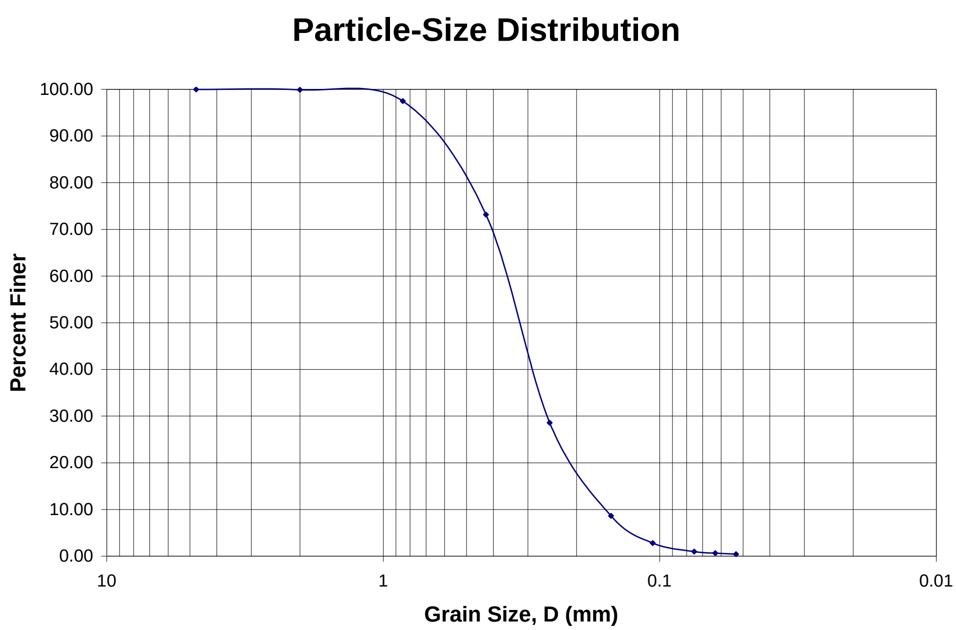

Figure 21: The grain size analysis of the soil in vadose zone at Hunter's Trace site

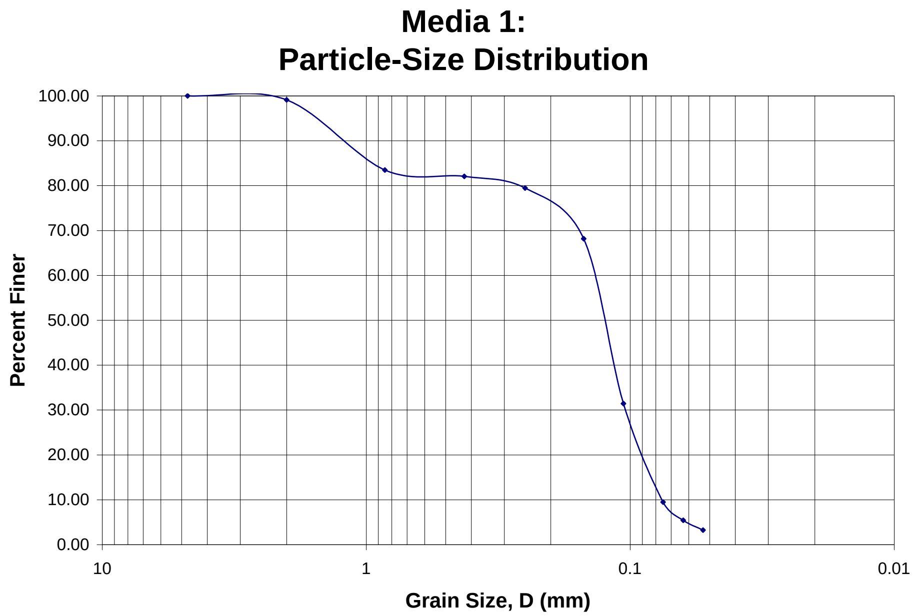

Figure 22: Gradation curve of media mix 1

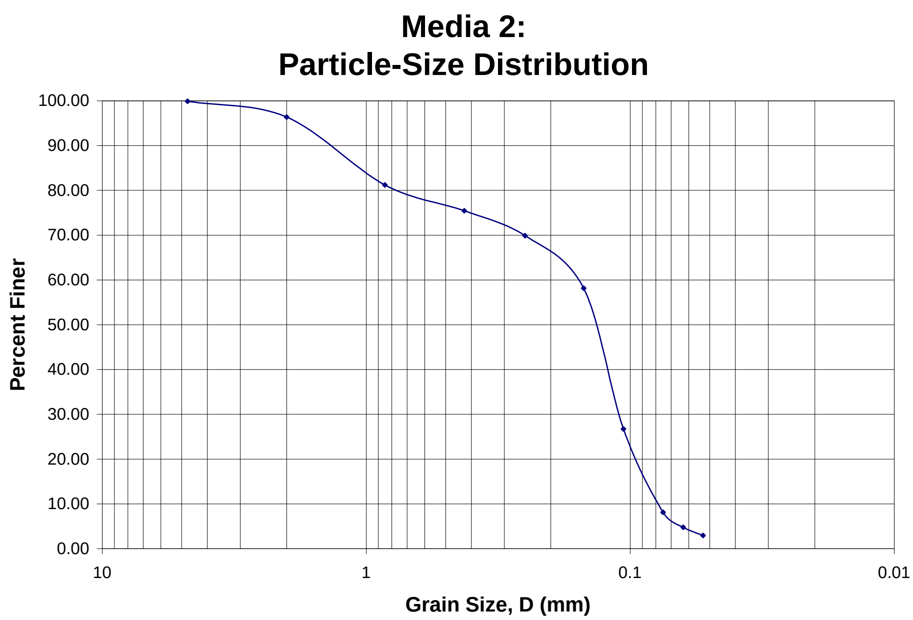

Figure 23: Gradation curve of media mix 2

Loading rate was identified by a series of lab-scale tests, which can be used as a control parameter of the biofiltration process in the field. The permeability of the Hunter's Trace soil was measured to be 24.6 inches per hour. However, the testing method requires the sample to be oven dried {ASTM D242-85(2007)} Standard practice for dry preparation of soil sample for particle size analysis and determination of soil constants}. The soil packed into the columns will not be oven dried, so permeability was also tested using a moist sample. The moist sample of Hunter's Trace soil had a permeability of 4.47 cm/hr (1.76 in/hr). The permeability of Media Mix 1 was measured to be 11.12 cm/hr (4.38 in/hr). The permeability of media mix 2 was measured to be 9.19 cm/hr (3.62 in/hr). The media mix soil properties obtained during materials characterization may be used to develop guidelines for stormwater treatment using filtration tanks/biofiltration reactors in both wet and dry ponds. Table 12 presents a summary of material characterization for the Hunter's Trace control soil and media mixes one and two.

Table 12: Summary of Material Characterization

	Hunter's Trace (dry sample)	**Hunter's Trace (moist sample)**	**Media Mix 1**	**Media Mix 2**
Density (g/cm^3)	1.56	1.73	1.41	1.44
Void Ratio	0.67	0.51	0.56	0.62
Porosity	0.40	0.34	0.36	0.38
Specific Gravity (Gs)	2.62	2.62	2.19	2.33
Surface Area (m^2/g)	-	-	0.129	0.242
Permeability (cm/hr)	62.48	4.47	4.38	3.62

Column Studies- Nitrate Results

Determination of Nitrate removal potential is essential for successful design and implementation of a system for Nitrate reducing filter media. Nitrate removal is presented in four parts: overall Nitrate reduction, unsaturated Nitrate reduction, saturated Nitrate reduction and saturated TN reduction.

Overall Nitrate Reduction

Overall Nitrate reduction presents the quantification of Nitrate reduction for the entire system including the unsaturated and saturated columns. The Nitrate removal mechanism within the column system is regarded as denitrification. Since denitrification takes place in anaerobic environments the majority of denitrification is expected to take place in the saturated zone. To determine overall Nitrate removal three pairs of columns containing two media mixes and a control were dosed with pond water augmented with approximately 0.40, 1.25 and 2.5 mg/L as Nitrate Nitrogen. Three complete experimental runs were conducted for each concentration. The test used to measure Nitrate measures Nitrate plus Nitrite, however Nitrite concentrations are relatively low and are therefore are considered negligible.

Table 13: Total System Nitrate Removal Efficiency for Approximate Nitrate Influent Concentration of 0.40 mg/L NO3-N

Control Run	Initial Concentration (mg/L NO_3-N) Top Column 1	Final Concentration (mg/L NO_3-N) Bottom Column 2	Removal Efficiency (%)
1	0.382	0.294	23.0
2	0.382	0.266	30.2
3	0.382	0.139	63.6
Average	0.382	0.233	38.9
Media 1 Run	Initial Concentration (mg/L NO_3-N) Top Column 3	Final Concentration (mg/L NO_3-N) Bottom Column 4	Removal Efficiency (%)
1	0.382	0.021	94.5
2	0.382	0.022	94.1
3	0.382	0.023	94.0
Average	0.382	0.022	94.2
Media 2 Run	Initial Concentration (mg/L NO_3-N) Top Column 5	Final Concentration (mg/L NO_3-N) Bottom Column 6	Removal Efficiency (%)
1	0.382	0.022	94.2
2	0.382	0.023	94.0
3	0.382	0.023	93.9
Average	0.382	0.023	94.1

Tables 13-15 summarize Nitrate removal efficiencies for the control case (columns 1 and 2), media 1 (columns 3 and 4), and media 2 (columns 5 and 6) given an initial Nitrate concentrations of 0.38, 1.26 and 2.53 mg/L NO_3-N. Where columns 1, 3 and 5 are unsaturated and columns 2, 4 and 6 are saturated. For media 1 and media 2 Tables 13-15 shows that increased influent Nitrate corresponds to increased Nitrate removal efficiency. For media 1 and 2 Nitrate average removal efficiencies begin at approximately 94% given an influent Nitrate concentration of 0.38 mg/L NO_3-N. Increasing the influent Nitrate concentration to 1.26 mg/L

NO_3-N and 2.5 mg/L NO_3-N yields Nitrate removal efficiencies of approximately 98% and 99%. At every Nitrate concentration media 1 averaged slightly higher Nitrate removals compared to media 2. The control varied in Nitrate reduction from about 23% to 75%. Different influent Nitrate concentrations influenced Nitrate removal efficiency with the control. For influent Nitrate of 1.26 mg/L NO_3-N average Nitrate removal efficiency was 70%.

Increasing influent Nitrate to 2.5 mg/L NO_3-N dropped the controls Nitrate removal efficiency in the control columns to 39%. The Nitrate removal efficiency for 0.38 mg/L NO_3-N influent Nitrate was highly variable from 23% to 63%. The high variabilty evidenced in Nitrate removal efficiency may be the result of inadequate flushing or an increase in denitrifying microbes.

Table 14: Total System Nitrate Removal Efficiency for Approximate Nitrate Influent Concentration of 1.25 mg/L NO3-N

Control Run	Initial Concentration (mg/L NO_3-N) Top Column 1	Final Concentration (mg/L NO_3-N) Bottom Column 2	Removal Efficiency (%)
1	1.269	0.312	75.4
2	1.269	0.391	69.2
3	1.269	0.438	65.4
Average	1.269	0.380	70.0
Media 1 Run	Initial Concentration (mg/L NO_3-N) Top Column 3	Final Concentration (mg/L NO_3-N) Bottom Column 4	Removal Efficiency (%)
1	1.269	0.023	98.2
2	1.269	0.022	98.2
3	1.269	0.023	98.2
Average	1.269	0.023	98.2
Media 2 Run	Initial Concentration (mg/L NO_3-N) Top Column 5	Final Concentration (mg/L NO_3-N) Bottom Column 6	Removal Efficiency (%)
1	1.269	0.025	98.0
2	1.269	0.023	98.2
3	1.269	0.024	98.1
Average	1.269	0.024	98.1

Table 15: Total System Nitrate Removal Efficiency for Approximate Nitrate Influent Concentration of 2.50 mg/L NO3-N

Control Run	Initial Concentration (mg/L NO_3-N) Top Column 1	Final Concentration (mg/L NO_3-N) Bottom Column 2	Removal Efficiency (%)
1	2.529	1.615	36.1
2	2.529	1.508	40.4
3	2.529	1.463	42.1
Average	2.529	1.529	39.5
Media 1 Run	Initial Concentration (mg/L NO_3-N) Top Column 3	Final Concentration (mg/L NO_3-N) Bottom Column 4	Removal Efficiency (%)
1	2.529	0.021	99.2
2	2.529	0.021	99.2
3	2.529	0.021	99.2
Average	2.529	0.021	99.2
Media 2 Run	Initial Concentration (mg/L NO_3-N) Top Column 5	Final Concentration (mg/L NO_3-N) Bottom Column 6	Removal Efficiency (%)
1	2.529	0.024	99.0
2	2.529	0.022	99.1
3	2.529	0.022	99.1
Average	2.529	0.023	99.1

Unsaturated Nitrate Reduction

In Table 16 average Nitrate removal efficiencies for the unsaturated columns are presented. The unsaturated control column (column 1) exhibited great variation throughout the given range of influent Nitrate concentrations. Unsaturated control column 1 added Nitrate ranging from 63% to near zero. Unsaturated control column 3 had Nitrate removal efficiencies ranging from 5% to 27% and unsaturated control column 5 had Nitrate removal efficiencies of 62% to 78%.

Table 16: Average Nitrate Removal Efficiency for Unsaturated Columns

Control Column 1	Initial Concentration (mg/L NO_3-N) Top Column 1	Final Concentration (mg/L NO_3-N) Bottom Column 1	Removal Efficiency (%)
Average n=3	0.382	0.626	-63.9
Average n=3	1.269	1.868	-47.3
Average n=3	2.529	2.526	0.1
Control Column 3	Initial Concentration (mg/L NO_3-N) Top Column 3	Final Concentration (mg/L NO_3-N) Bottom Column 3	Removal Efficiency (%)
Average n=3	0.382	0.362	5.3
Average n=3	1.269	0.921	27.4
Average n=3	2.529	1.958	22.6
Control Column 5	Initial Concentration (mg/L NO_3-N) Top Column 5	Final Concentration (mg/L NO_3-N) Bottom Column 5	Removal Efficiency (%)
Average n=3	0.382	0.141	63.0
Average n=3	1.269	0.268	78.9
Average n=3	2.529	0.798	68.5

The unsaturated columns were filled with same soil and compacted using the same technique. Identical flushing was performed for each column pair. A partial explanation for Nitrate addition in column 1 is the nitrification of Ammonia to Nitrate. Table 17 shows the average Ammonia removal in column 1 for each Nitrate concentration. Note that each pond water sample contains a different initial concentration of Ammonia.

Table 17: Average Ammonia Removal in Column 1

Control Column 1	Initial Concentration (mg/L NO_3-N) Top Column 1	Initial Concentration (mg/L NH_3-N) Top Column 1	Final Concentration (mg/L NH_3-N) Bottom Column 1	Removal Efficiency (%)
Average n=3	0.38	0.015	0.004	74.5
Average n=3	1.26	0.028	0.013	54.7
Average n=3	2.53	0.040	0.025	37.0

The variation in removal efficiencies of the unsaturated columns may be caused by the conditions within the unsaturated columns. Portions of unsaturated columns 3 and 5 may have saturated conditions which may promote growth of denitrifying bacteria. Different conditions within each unsaturated control column may be caused by non homogeneous control soil. The non homogeneous soil may be responsible for nitrate reduction in control column 3 and control column 5.

Saturated Nitrate Reduction

The saturated zone is considered anaerobic, anaerobic conditions are necessary for denitrifying bacteria to carry out denitrification. For media 1 and 2 Nitrate removal efficiency is directly influenced by the initial Nitrate concentration entering the saturated column. Shown in

Tables 18-20 for media mix 1 (column 4) and media mix 2 (column 6) Nitrate removal efficiency decreases as influent Nitrate concentration decreases. Consistently, regardless of influent Nitrate concentration media 1 and 2 reduce Nitrate too approximately 0.022-0.024 mg/L NO_3-N. This approximate concentration may be refered to as the endpoint of denitrification. Final concentration of Nitrate is slightly lower for media mix 1 than media mix 2. For media mixes 1 and 2 Nitrate removal efficiency ranged from 60% to 98%. The seemingly low Nitrate removal value of 60% may be deceiving. The 60% efficiency was the result of a relatively low initial Nitrate concentration calculated as the result of a relatively low initial Nitrate concentration. The Nitrate removal efficiencies of the control, column 2 appear to be dependant on the inital Nitrate concentartion. Data from Tables 19 and 20 suggest that final Nitrate concentrations in the control increase as initial Nitrate concentrations increase. Tables 18-20 showed Nitrate removal efficiencies for control soil ranging from 37%-79%, however the control soil did not exhibit a consistant final concentration of Nitrate similar to media mixes 1 and 2. The results suggest that saturated control soil may remove a certain percentage of Nitrate from stormwater, however media 1 and 2 provide for consistantly high Nitrate removal efficiencies and relatively constant effluent Nitrate concentrations.

The Nitrate removal efficiencies found in Table 20 are slightly higher than a similar experiment using media mixes 1 and 2. The previous study batch fed augmented stormwater of Nitrate concentration 2.5 mg/L as NO_3- N into 12 inch columns. For the previous experiment Nitrate removal efficiencies for 3 hour and 5 hour retention times were 90.28% and 90.83% (Chang, 2008). For total system influent of 2.53 mg/L as NO_3- N current experimentation provided approximately 97%-99% Nitrate removal efficiencies at retention time 4 hours for media mix 1 and media mix 2. The Nitrate removal efficiencies of 97%-99% from Table 20 represent the entire saturated column which has a retention time of 14 hours. However most if not all denitrification takes place within time 4 hours and possibly sooner. Therefore Nitrate removal efficiency at time 4 hours is approximately equal to Nitrate removal efficieny at time 14 hours. The previous and current experiment may not be directly compared because influent saturated Nitrate concentrations for media mix 1 and media mix 2 varies from approximately 0.8- 2 mg/L as NO_3- N. Lack of bacterial contact may be attributed to increased wall effects caused by smaller column size. Dosing the columns using a batch feed instead of continuous feed may be decreasing Nitrate removal efficiency. Both studies suggest that media mix 1 and media mix 2 are effective at reducing Nitrate within augmented stormwater.

Table 18: Nitrate Removal Efficiency for Saturated Columns Given System Influent Nitrate Concentration 0.40 mg/L NO3-N

Control Run	Initial Concentration (mg/L NO_3-N) Top Column 2	Final Concentration (mg/L NO_3-N) Bottom Column 2	Removal Efficiency (%)
1	0.556	0.294	47.1
2	0.634	0.266	58.0
3	0.687	0.139	79.8
Average	0.626	0.233	61.6
Media 1 Run	Initial Concentration (mg/L NO_3-N) Top Column 4	Final Concentration (mg/L NO_3-N) Bottom Column 4	Removal Efficiency (%)
1	0.383	0.021	94.6
2	0.358	0.022	93.7
3	0.344	0.023	93.4
Average	0.362	0.022	93.9
Media 2 Run	Initial Concentration (mg/L NO_3-N) Top Column 6	Final Concentration (mg/L NO_3-N) Bottom Column 6	Removal Efficiency (%)
1	0.229	0.022	90.4
2	0.137	0.023	83.3
3	0.058	0.023	60.2
Average	0.141	0.023	78.0

Table 19: Nitrate Removal Efficiency for Saturated Columns Given System Influent Nitrate Concentration 1.25 mg/L NO3-N

Control Run	Initial Concentration (mg/L NO_3-N) Top Column 2	Final Concentration (mg/L NO_3-N) Bottom Column 2	Removal Efficiency (%)
1	1.534	0.312	79.7
2	1.888	0.391	79.3
3	2.184	0.438	79.9
Average	1.868	0.380	79.6
Media 1 Run	Initial Concentration (mg/L NO_3-N) Top Column 4	Final Concentration (mg/L NO_3-N) Bottom Column 4	Removal Efficiency (%)
1	0.612	0.023	96.3
2	1.033	0.022	97.8
3	1.118	0.023	98.0
Average	0.921	0.023	97.4
Media 2 Run	Initial Concentration (mg/L NO_3-N) Top Column 6	Final Concentration (mg/L NO_3-N) Bottom Column 6	Removal Efficiency (%)
1	0.216	0.025	88.5
2	0.312	0.023	92.5
3	0.276	0.024	91.2
Average	0.268	0.024	90.7

Table 20: Nitrate Removal Efficiency for Saturated Columns Given System Influent Nitrate Concentration 2.5 mg/L NO3-N

Control Run	Initial Concentration (mg/L NO_3-N) Top Column 2	Final Concentration (mg/L NO_3-N) Bottom Column 2	Removal Efficiency (%)
1	2.605	1.615	38.0
2	2.524	1.508	40.3
3	2.449	1.463	40.2
Average	2.526	1.529	39.5
Media 1 Run	Initial Concentration (mg/L NO_3-N) Top Column 4	Final Concentration (mg/L NO_3-N) Bottom Column 4	Removal Efficiency (%)
1	1.945	0.021	98.9
2	1.976	0.021	98.9
3	1.954	0.021	98.9
Average	1.958	0.021	98.9
Media 2 Run	Initial Concentration (mg/L NO_3-N) Top Column 6	Final Concentration (mg/L NO_3-N) Bottom Column 6	Removal Efficiency (%)
1	0.781	0.024	96.9
2	0.817	0.022	97.3
3	0.795	0.022	97.2
Average	0.798	0.023	97.1

The influent Nitrate concentrations into the saturated columns varied for media mix 1 and media mix 2. Influent Nitrate concentrations for media 1 and media 2 saturated zones varied with each total system influent Nitrate concentration 0.40, 1.25, 2.5 NO_3-N. For Nitrate system influent of approximately 0.40 mg/L NO_3-N the influent Nitrate concentration range for the saturated media 1 column (column 4) and the saturated media 2 column (column 6) was 0.34 to 0.38 mg/L NO_3-N and 0.05 to 0.22 mg/L NO_3-N respectively. Table 21 shows the influent

Nitrate concentration range for the saturated media 1 column and the saturated media 2 column. The variation of saturated Nitrate influent values was discussed in the previous section titled "Unsaturated Results".

Table 21: Influent Nitrate Concentrations for Saturated Media 1 and 2

Media	Approximate Total System Influent Nitrate Concentration (mg/L as NO3-N)	Range of Influent Nitrate Concentrations for Saturated Columns (mg/L as NO_3-N)
1	0.4	0.344-0.382
2	0.4	0.058-0.228
1	1.25	0.611-1.11
2	1.25	0.215-0.311
1	2.5	1.94-1.97
2	2.5	0.781-0.816

In Figures 24-26 Nitrate removal for the saturated columns given system Nitrate influent concentrations of 0.38, 1.26 and 2.53 mg/L NO_3-N are shown.

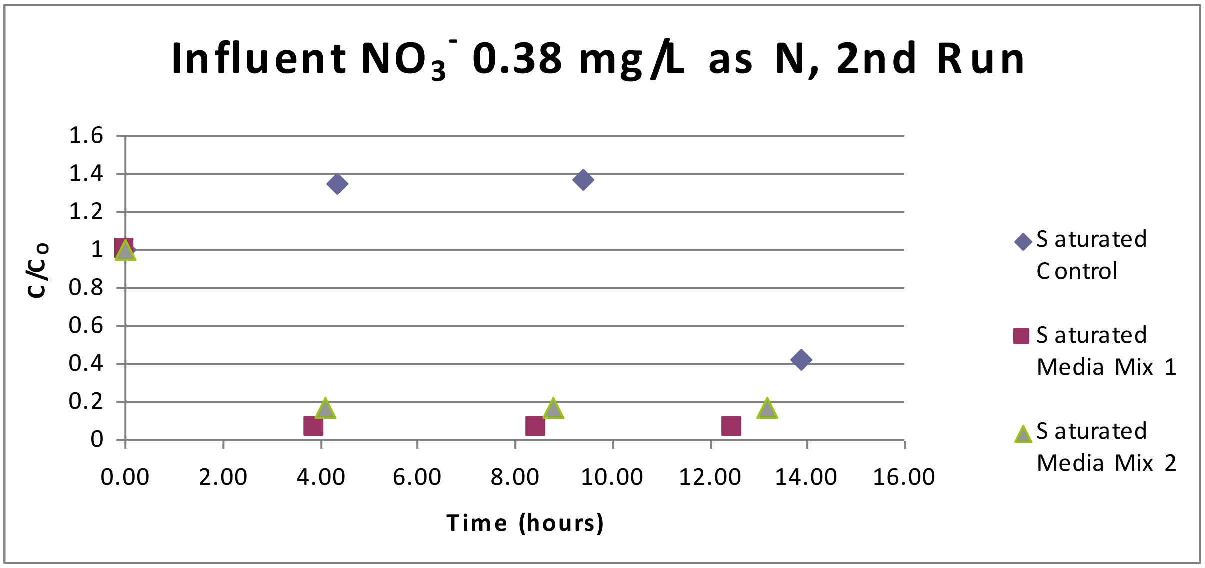

Figure 24: Nitrate Removal for Saturated Columns given 0.38 mg/L NO3-N influent

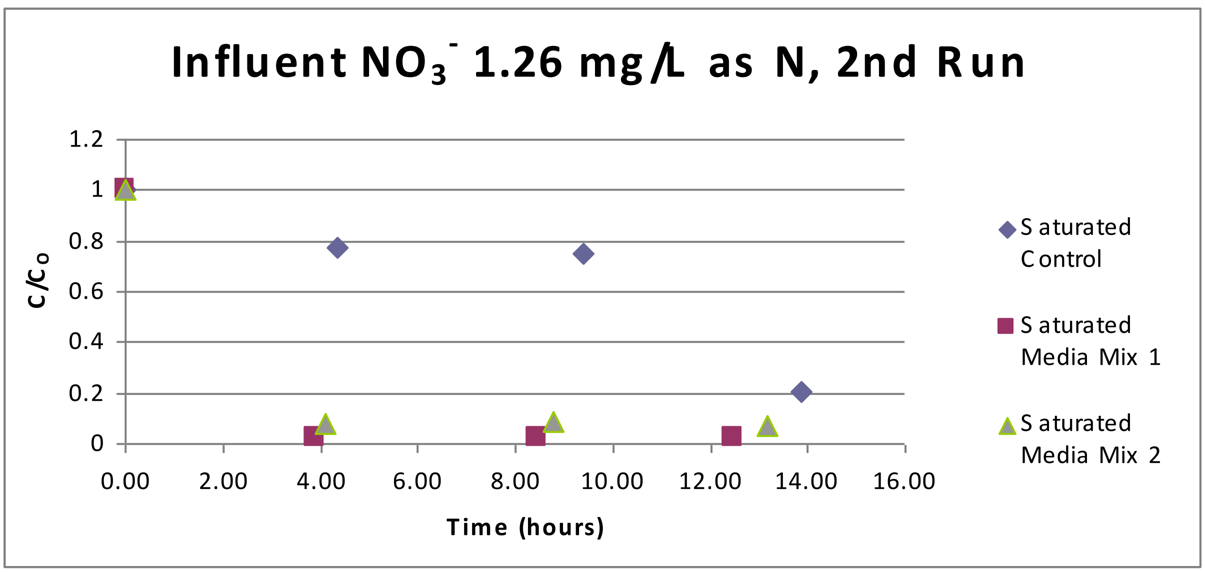

Figure 25: Nitrate Removal for Saturated Columns given 1.26 mg/L NO3-N influent

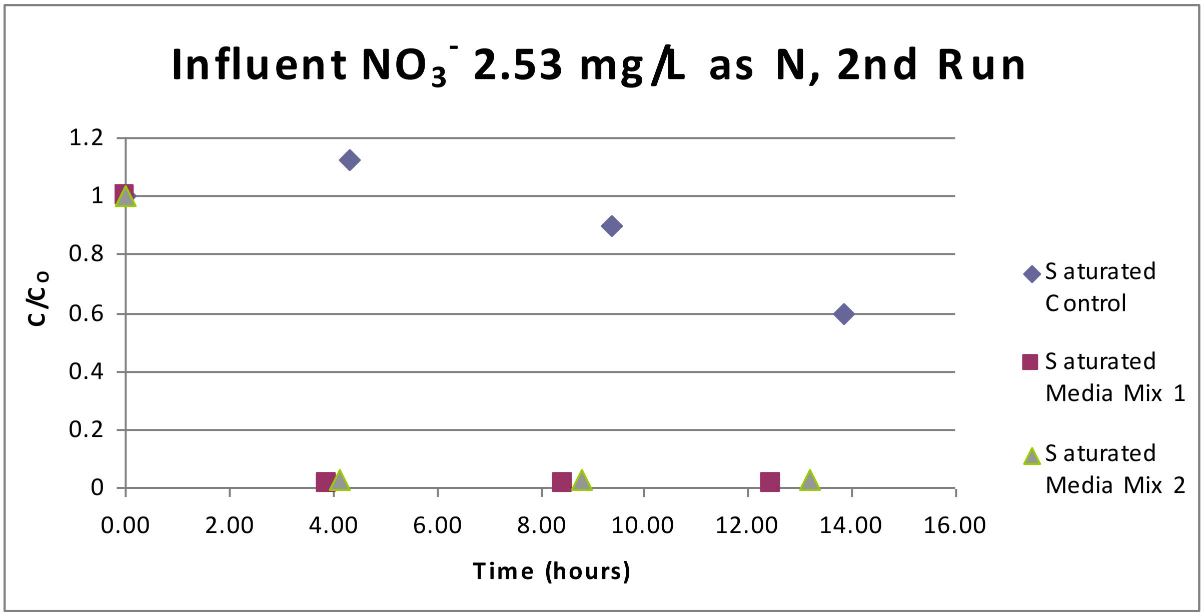

Figure 26: Nitrate Removal for Saturated Columns given 2.53 mg/L NO3-N influent

The dissolved oxygen DO measurements suggest the saturated columns provide the anaerobic environment necessary for microbial denitrification. Dissolved oxygen was measured during all Nitrate addition scenarios. The average DO measurements for Nitrate addition are shown in Table 22. The reservoir DO varies from 2.46 to 3.01mg/L which is too high to promote denitrifying bacterial growth. As the water permeates through the saturated column the DO concentration decreases. The decreased DO enables the growth of denitrifying bacteria. Referencing Figures 24-26, most denitrification takes place before the second sampling port. Therefore it is expected that DO values at the 2nd sampling port would be relatively low. Shown in Table 22, DO values for saturated port 2 vary from 0.18 to 0.44 mg/L. The low DO concentration is conducive for denitrifying bacteria growth. Errors in obtaining correct DO measurements may be attributed to bubbles in the tube that connected the sampling port and the DO sampling probe.

Table 22: Average DO Measurements for Nitrate Addition

Average Control DO		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.56
saturated port 1	0.00	0.78
saturated port 2	4.33	0.44
saturated port 3	9.38	0.22
bottom of saturated	13.85	0.14
Average Media 1 DO		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.46
saturated port 1	0.00	0.67
saturated port 2	3.90	0.27
saturated port 3	8.45	0.18
bottom of saturated	12.47	0.10
Average Media 2 DO		
Location	Detention time (hrs)	DO mg/L
reservoir	-	3.01
saturated port 1	0.00	0.66
saturated port 2	4.12	0.18
saturated port 3	8.77	0.39
bottom of saturated	13.17	0.19

Saturated TN Reduction

Total Nitrogen TN removal for the saturated columns varied for each influent Nitrate concentration. For influent Nitrate concentration 0.38 mg/L NO_3^{-}-N the average removal for the saturated control, media 1 mix and media 2 mix was shown in Table 23 to be 31.18%, -28.66 % and -69.14%. The negative removal efficiencies for media mix 1 and media mix 2 indicate TN addition of 28.66 % and 69.14%. Shown in Table 24 the TN removal efficiency for Nitrate system influent of concentration 1.25 mg/L NO_3-N. The average removal of the control decreases to 25.7% and the average TN removal of media mix 1 increase to 66.58%. For media mix 2 the average TN addition decreases from 69.14% to 13.61%. For influent Nitrate concentration 2.5 mg/L NO_3-N, media mix 1 and media mix 2 average TN removals of 75.81% and 86.84%. At this influent Nitrate concentration the control removes an average of 41.51% of TN. Based on these results media mix 1 and media mix 2 may not be effective at reducing Total Nitrogen for an influent Nitrate concentration of 0.38 mg/L NO_3-N. Media mix 2 may not be effective at reducing Total Nitrogen for an influent Nitrate concentration of 1.26 mg/L NO_3-N. Both media mix 1 and media mix 2 are effective in reducing Total Nitrogen for an influent Nitrate concentration of 2.53 mg/L NO_3-N.

Table 23: Total Nitrogen Removal Efficiency for Saturated Columns Given System Influent Nitrate Concentration 0.40 mg/L N

Control Run	Initial Concentration (mg/L N) Top Column 2	Final Concentration (mg/L N) Bottom Column 2	Removal Efficiency (%)
1	1.427	0.976	31.63
2	1.377	0.825	40.06
3	1.377	1.076	21.85
Average	1.394	0.959	31.18
Media 1 Run	Initial Concentration (mg/L N) Top Column 4	Final Concentration (mg/L N) Bottom Column 4	Removal Efficiency (%)
1	0.976	1.327	-35.97
2	0.976	1.227	-25.70
3	0.825	1.026	-24.30
Average	0.926	1.193	-28.66
Media 2 Run	Initial Concentration (mg/L N) Top Column 6	Final Concentration (mg/L N) Bottom Column 6	Removal Efficiency (%)
1	0.474	1.277	-169.17
2	0.525	0.625	-19.12
3	0.525	0.625	-19.12
Average	0.508	0.842	-69.14

Table 24: Total Nitrogen Removal Efficiency for Saturated Columns Given System Influent Nitrate Concentration 1.25 mg/L N

Control Run	Initial Concentration (mg/L N) Top Column 2	Final Concentration (mg/L N) Bottom Column 2	Removal Efficiency (%)
1	2.430	1.327	45.40
2	2.079	1.728	16.88
3	2.029	1.728	14.83
Average	2.180	1.595	25.70
Media 1 Run	Initial Concentration (mg/L N) Top Column 4	Final Concentration (mg/L N) Bottom Column 4	Removal Efficiency (%)
1	2.481	0.976	60.66
2	4.236	1.277	69.86
3	3.985	1.227	69.22
Average	3.567	1.160	66.58
Media 2 Run	Initial Concentration (mg/L N) Top Column 6	Final Concentration (mg/L N) Bottom Column 6	Removal Efficiency (%)
1	1.126	0.625	44.53
2	0.474	0.625	-31.72
3	0.374	0.575	-53.63
Average	0.658	0.608	-13.61

Table 25: Total Nitrogen Removal Efficiency for Saturated Columns Given System Influent Nitrate Concentration 2.5 mg/L N

Control Run	Initial Concentration (mg/L N) Top Column 2	Final Concentration (mg/L N) Bottom Column 2	Removal Efficiency (%)
1	2.330	1.979	15.07
2	3.183	1.427	55.15
3	3.233	1.477	54.30
Average	2.915	1.628	41.51
Media 1 Run	Initial Concentration (mg/L N) Top Column 4	Final Concentration (mg/L N) Bottom Column 4	Removal Efficiency (%)
1	1.929	0.876	54.60
2	3.283	0.474	85.55
3	3.333	0.424	87.27
Average	2.848	0.591	75.81
Media 2 Run	Initial Concentration (mg/L N) Top Column 6	Final Concentration (mg/L N) Bottom Column 6	Removal Efficiency (%)
1	1.829	0.224	87.77
2	2.029	0.324	84.04
3	1.979	0.224	88.70
Average	1.946	0.257	86.84

Shown in Tables 23-25 media mix 1 and media mix 2 TN removal efficiency increases as influent Nitrate concentration increases. Similar results are shown in the "Saturated Nitrate Reduction" section of this chapter. As influent Nitrate concentration increased so did the Nitrate removal efficiency. For Nitrate influents of 0.40 and 1.25 mg/L NO_3-N, media mix 1 and media mix 2 added TN to the system. For Nitrate influent of 2.5 mg/L NO_3-N media mix 1 and media mix 2 were effective at removing TN from the system. The TN addition noted in influent concentrations 0.40 and 1.25 NO_3-N for media mix 1 and media mix 2 were caused by an increase in Ammonia. Media mix 1 and media mix 2 both added Ammonia to the water. Shown in Tables 26-28 Ammonia addition for media 1 mix and media mix 2 was relatively consistent and independent of the influent Nitrate concentration. As influent Nitrate increases TN removal performance will be less dependent on the Ammonia concentration and more dependent of Nitrate removal. This logic would explain the increased TN removal efficiencies for media mix 1 and media mix 2 given an influent Nitrate concentration of 2.5 mg/L NO_3-N.

Table 26: Ammonia Input for Saturated Columns Given System Influent Nitrate Concentration 0.40 mg/L N

Control Run	Initial Concentration (mg/L NH_3-N) Top Column 2	Final Concentration (mg/L NH_3-N) Bottom Column 2	Ammonia Added mg/L NH_3-N
1	0.000	0.139	0.139
2	0.001	0.184	0.183
3	0.010	0.219	0.209
Average	0.004	0.181	0.177
Media 1 Run	Initial Concentration (mg/L NH_3-N) Top Column 4	Final Concentration (mg/L NH_3-N) Bottom Column 4	Ammonia Added mg/L NH_3-N
1	0.003	0.022	0.018
2	0.007	0.028	0.020
3	0.005	0.038	0.033
Average	0.005	0.029	0.024
Media 2 Run	Initial Concentration (mg/L NH_3-N) Top Column 6	Final Concentration (mg/L NH_3-N) Bottom Column 6	Ammonia Added mg/L NH_3-N
1	0.005	0.119	0.115
2	0.003	0.124	0.120
3	0.001	0.135	0.134
Average	0.003	0.126	0.123

Table 27: Ammonia Input for Saturated Columns Given System Influent Nitrate Concentration 1.25 mg/L N

Control Run	Initial Concentration (mg/L NH_3-N) Top Column 2	Final Concentration (mg/L NH_3-N) Bottom Column 2	Ammonia Added mg/L NH_3-N
1	0.016	0.249	0.233
2	0.004	0.273	0.269
3	0.018	0.287	0.269
Average	0.013	0.270	0.257
Media 1 Run	Initial Concentration (mg/L NH_3-N) Top Column 4	Final Concentration (mg/L NH_3-N) Bottom Column 4	Ammonia Added mg/L NH_3-N
1	0.030	0.042	0.011
2	0.016	0.100	0.085
3	0.034	0.113	0.079
Average	0.026	0.085	0.059
Media 2 Run	Initial Concentration (mg/L NH_3-N) Top Column 6	Final Concentration (mg/L NH_3-N) Bottom Column 6	Ammonia Added mg/L NH_3-N
1	0.004	0.075	0.071
2	0.010	0.092	0.082
3	0.018	0.107	0.089
Average	0.011	0.091	0.081

Table 28: Ammonia Input for Saturated Columns Given System Influent Nitrate Concentration 2.5 mg/L N

Control Run	Initial Concentration (mg/L NH_3-N) Top Column 2	Final Concentration (mg/L NH_3-N) Bottom Column 2	Ammonia Added mg/L NH_3-N
1	0.030	0.397	0.367
2	0.012	0.399	0.388
3	0.033	0.401	0.368
Average	0.025	0.399	0.374
Media 1 Run	Initial Concentration (mg/L NH_3-N) Top Column 4	Final Concentration (mg/L NH_3-N) Bottom Column 4	Ammonia Added mg/L NH_3-N
1	0.054	0.106	0.052
2	0.025	0.121	0.096
3	0.052	0.111	0.059
Average	0.043	0.112	0.069
Media 2 Run	Initial Concentration (mg/L NH_3-N) Top Column 6	Final Concentration (mg/L NH_3-N) Bottom Column 6	Ammonia Added mg/L NH_3-N
1	0.006	0.088	0.082
2	0.001	0.065	0.064
3	0.010	0.060	0.051
Average	0.005	0.071	0.066

Table 26 shows Ammonia addition for media 2 is greater than Ammonia addition in Tables 27 and 28. Inadequate flushing may be responsible for increased Ammonia addition for media 2 given an influent Nitrate concentration of 0.40 mg/L NO_3-N.

Column Studies- Ortho Phosphate Results

Determination of Phosphorus removal potential is essential for successful design and implementation of Phosphorus reducing filter media. Phosphorus removal is presented in four parts: overall Orthophosphate reduction, unsaturated Orthophosphate reduction, saturated Orthophosphate reduction and saturated Total Phosphorus reduction.

Overall Orthophosphate Reduction

Overall Orthophosphate reduction presents the quantification of Orthophosphate reduction for the entire system including the unsaturated and saturated columns. The Orthophosphate removal mechanism within the column system is regarded as sorption. Sorption may take place within the unsaturated and saturated zones and therefore Orthophosphate removal is expected to take place within both unsaturated and saturated zones. To determine overall Orthophosphate removal three pairs of columns containing two media mixes and a control were dosed with pond water augmented with approximately 0.125, 0.361 and 0.785 mg/L as PO_4-P. Three complete experimental runs were conducted for each concentration.

Table 29: Total System Orthophosphate Removal Efficiency for Approximate PO4-P Influent Concentration of 0.125 mg/L PO4-P

Control Run	Initial Concentration (mg/L PO_4-P) Top Column 1	Final Concentration (mg/L PO_4-P) Bottom Column 2	Removal Efficiency (%)
1	0.125	0.294	-135.8
2	0.125	0.280	-124.3
3	0.125	0.336	-169.3
Average	0.125	0.304	-143.1
Media 1 Run	Initial Concentration (mg/L PO_4-P) Top Column 3	Final Concentration (mg/L PO_4-P) Bottom Column 4	Removal Efficiency (%)
1	0.125	0.071	42.8
2	0.125	0.044	64.8
3	0.125	0.067	46.0
Average	0.125	0.061	51.2
Media 2 Run	Initial Concentration (mg/L PO_4-P) Top Column 5	Final Concentration (mg/L PO_4-P) Bottom Column 6	Removal Efficiency (%)
1	0.125	0.099	20.9
2	0.125	0.075	39.7
3	0.125	0.078	37.6
Average	0.125	0.084	32.7

Tables 29-31 summarize Orthophosphate removal efficiencies for the control case (columns 1 and 2), media 1 (columns 3 and 4), and media 2 (columns 5 and 6) given an initial Orthophosphate concentrations of 0.125, 0.361 and 0.785 mg/L PO_4-P. Where columns 1, 3 and 5 are unsaturated and columns 2, 4 and 6 are saturated.

For the control, media mix 1 and media mix 2 increased influent Orthophosphate corresponds to increased Orthophosphate removal efficiency shown in Tables 29-31. Throughout the tested influent Orthophospahte concentrations media mix 1 consistantly outperformed the control and media mix 2. For media mix 1 and media mix 2, average Orthophospahte removal efficiencies begin at approximately 51.2% and 32.7% given an influent Orthophosphate concentration of 0.125 mg/L PO_4-P. At this concentration the control added an average of 143.1% of the original Orthophosphate. For media mix 1 and media mix 2 increasing the influent Orthophosphate concentration to 0.361 mg/L PO_4-P and 0.785 mg/L PO_4-P yields average Orthophosphate removal efficiencies of approximately 86%, 91% and 84%, 86%. At every Orthophosphate concentration media mix 1 averaged higher Nitrate removals compared to media mix 2. The control varied in Orthophosphate addtion and reduction from 143% Orthophosphate addition to 55% Orthophosphate reduction. Different influent Orthophosphate concentrations influenced Orthophosphate removal efficiency with the control. For influent Orthophosphate of 0.125 mg/L PO_4-P, average Orthophosphate addition was 143.1%. Increasing influent Orthophosphate to 0.785 mg/L PO_4-P increased the controls Orthophosphate average removal efficiency to 55.2%.

Table 30: Total System Orthophosphate Removal Efficiency for Approximate PO4-P Influent Concentration of 0.361 mg/L PO4-P

Control Run	Initial Concentration (mg/L PO_4-P) Top Column 1	Final Concentration (mg/L PO_4-P) Bottom Column 2	Removal Efficiency (%)
1	0.361	0.293	18.8
2	0.361	0.285	21.0
3	0.361	0.302	16.3
Average	0.361	0.294	18.7
Media 1 Run	Initial Concentration (mg/L PO_4-P) Top Column 3	Final Concentration (mg/L PO_4-P) Bottom Column 4	Removal Efficiency (%)
1	0.361	0.043	88.2
2	0.361	0.077	78.8
3	0.361	0.031	91.4
Average	0.361	0.050	86.1
Media 2 Run	Initial Concentration (mg/L PO_4-P) Top Column 5	Final Concentration (mg/L PO_4-P) Bottom Column 6	Removal Efficiency (%)
1	0.361	0.054	84.9
2	0.361	0.070	80.6
3	0.361	0.049	86.4
Average	0.361	0.058	84.0

Table 31: Total System Orthophosphate Removal Efficiency for Approximate PO4-P Influent Concentration of 0.785 mg/L PO4-P

Control Run	Initial Concentration (mg/L PO_4-P) Top Column 1	Final Concentration (mg/L PO_4-P) Bottom Column 2	Removal Efficiency (%)
1	0.785	0.339	56.8
2	0.785	0.358	54.3
3	0.785	0.357	54.5
Average	0.785	0.351	55.2
Media 1 Run	Initial Concentration (mg/L PO_4-P) Top Column 3	Final Concentration (mg/L PO_4-P) Bottom Column 4	Removal Efficiency (%)
1	0.785	0.099	87.4
2	0.785	0.048	93.9
3	0.785	0.057	92.7
Average	0.785	0.068	91.4
Media 2 Run	Initial Concentration (mg/L PO_4-P) Top Column 5	Final Concentration (mg/L PO_4-P) Bottom Column 6	Removal Efficiency (%)
1	0.785	0.120	84.8
2	0.785	0.096	87.8
3	0.785	0.103	86.9
Average	0.785	0.106	86.5

Unsaturated Orthophosphate Reduction

In Table 32 average Orthophosphate removal efficiencies for the unsaturated columns are presented. The unsaturated control column (column 1) exhibited great variation throughout the given range of influent Orthophosphate concentrations. Column 1 reduced Orthophosphate from 28% to 75%. Column 3 removal efficiencies ranged from 5% Orthophosphate addition to 78% Orthophosphate reduction. Column 5 removal efficiencies ranged from 19% Orthophosphate addition to 73% Orthophosphate reduction. Shown in Table 32 for every unsaturated control column (columns 1,3,5) removal efficiency increases as influent Orthophosphate concentration increases.

Table 32: Average Orthophosphate Removal Efficiency for Unsaturated Columns

Control Column 1	Initial Concentration ($mg/L\ PO_4$-P) Top Column 1	Final Concentration ($mg/L\ PO_4$-P) Bottom Column 1	Removal Efficiency (%)
Average n=3	0.125	0.090	27.9
Average n=3	0.361	0.114	68.5
Average n=3	0.785	0.198	74.7
Media Mix 1 Column 3	Initial Concentration ($mg/L\ PO_4$-P) Top Column 3	Final Concentration ($mg/L\ PO_4$-P) Bottom Column 3	Removal Efficiency (%)
Average n=3	0.125	0.132	-5.4
Average n=3	0.361	0.150	58.5
Average n=3	0.785	0.171	78.3
Media Mix 2 Column 5	Initial Concentration ($mg/L\ PO_4$-P) Top Column 5	Final Concentration ($mg/L\ PO_4$-P) Bottom Column 5	Removal Efficiency (%)
Average n=3	0.125	0.149	-19
Average n=3	0.361	0.150	58.5
Average n=3	0.785	0.209	73.3

Saturated Orthophosphate Reduction

For media mix 1 and media mix 2 average Orthophosphate removal efficiency ranges from approximately 42% to 67%. There is no concrete relationship between influent Orthophosphate concentration and Orthophosphate removal efficiency. Orthophosphate removal efficiencies for the saturated columns are shown in Tables 33-35.

The saturated influent Orthophosphate values tend to vary despite an increased system influent Orthophosphate concentration. This is particularly evident for Orthophosphate system influent values of 0.125 and 0.361 mg/L PO_4-P. For these influent Orthophosphate system concentrations the influent concentrations to the saturated columns remain similar or decrease. This would suggest that the unsaturated columns are within some level of sorption capacity. This sorption capacity is overcome when total system influent Orthophosphate is 0.785 mg/L PO_4-P. At this influent Orthophosphate concentration the Orthophosphate concentration to the saturated column is consistently higher than the two smaller concentrations.

Shown in Tables 33-35 media mix 1 consistently outperforms media mix 2 with respect to Orthophosphate removal efficiency. In the tested Orthophosphate concentrations on average media mix 1 removes approximately 10%-20% more Orthophosphate than media mix 2. In every Orthophosphate concentration tested the control adds Orthophosphate, however as the influent Orthophosphate concentration increases the average percentage of Orthophosphate added decreases. For an Orthophospahte influent of 0.125 mg/L PO_4-P the control adds an average of 250% the original Orthophospahte. At Orthophosphate influent concentrations of 0.361 and

0.785 mg/L PO_4-P, the control adds an average of approximately 161% and 136% of the original Orthophospahte. These results suggest that media mix 1 and media mix 2 are more effective than the control for removing Orthophoshate.

Table 33: Orthophosphate Removal Efficiency for Saturated Columns Given System Influent Orthophosphate Concentration 0.125 mg/L PO4-P

Control Run	Initial Concentration (mg/L PO_4-P) Top Column 2	Final Concentration (mg/L PO_4-P) Bottom Column 2	Removal Efficiency (%)
1	0.069	0.294	-328.2
2	0.109	0.280	-156.5
3	0.092	0.336	-264.5
Average	0.090	0.304	-249.7
Media 1 Run	Initial Concentration (mg/L PO_4-P) Top Column 4	Final Concentration (mg/L PO_4-P) Bottom Column 4	Removal Efficiency (%)
1	0.131	0.071	45.7
2	0.137	0.044	67.8
3	0.127	0.067	47.1
Average	0.132	0.061	53.5
Media 2 Run	Initial Concentration (mg/L PO_4-P) Top Column 6	Final Concentration (mg/L PO_4-P) Bottom Column 6	Removal Efficiency (%)
1	0.194	0.099	49.1
2	0.137	0.075	44.9
3	0.116	0.078	32.7
Average	0.149	0.084	42.2

Table 34: Orthophosphate Removal Efficiency for Saturated Columns Given System Influent Orthophosphate Concentration 0.361 mg/L PO4-P

Control Run	Initial Concentration (mg/L PO_4-P) Top Column 2	Final Concentration (mg/L PO_4-P) Bottom Column 2	Removal Efficiency (%)
1	0.129	0.293	-127.6
2	0.100	0.285	-185.1
3	0.112	0.302	-170.3
Average	0.114	0.294	-161.0
Media 1 Run	Initial Concentration (mg/L PO_4-P) Top Column 4	Final Concentration (mg/L PO_4-P) Bottom Column 4	Removal Efficiency (%)
1	0.144	0.043	70.5
2	0.157	0.077	51.4
3	0.147	0.031	79.0
Average	0.150	0.050	66.9
Media 2 Run	Initial Concentration (mg/L PO_4-P) Top Column 6	Final Concentration (mg/L PO_4-P) Bottom Column 6	Removal Efficiency (%)
1	0.094	0.054	41.8
2	0.130	0.070	46.1
3	0.131	0.049	62.6
Average	0.118	0.058	50.2

Table 35: Orthophosphate Removal Efficiency for Saturated Columns Given System Influent Orthophosphate Concentration 0.785 mg/L PO4-P

Control Run	Initial Concentration (mg/L PO_4-P) Top Column 2	Final Concentration (mg/L PO_4-P) Bottom Column 2	Removal Efficiency (%)
1	0.310	0.339	-9.3
2	0.086	0.358	-318.1
3	0.199	0.357	-79.2
Average	0.198	0.351	-135.5
Media 1 Run	Initial Concentration (mg/L PO_4-P) Top Column 4	Final Concentration (mg/L PO_4-P) Bottom Column 4	Removal Efficiency (%)
1	0.195	0.099	49.4
2	0.155	0.048	69.1
3	0.161	0.057	64.7
Average	0.171	0.068	61.1
Media 2 Run	Initial Concentration (mg/L PO_4-P) Top Column 6	Final Concentration (mg/L PO_4-P) Bottom Column 6	Removal Efficiency (%)
1	0.284	0.120	57.9
2	0.130	0.096	26.1
3	0.214	0.103	51.9
Average	0.209	0.106	45.3

The influent Orthophosphate concentrations to the saturated columns are similar for media mix 1 and media mix 2. For Orthophosphate system influent of approximately 0.125 mg/L PO_4-P the influent Orthophosphate concentration range for the saturated media mix 1 column (column 4) and the saturated media mix 2 column (column 6) was 0.127 to 0.137 mg/L PO_4-P and 0.116 to 0.194 mg/L PO_4-P respectively. Shown in Table 36 the influent Orthophosphate concentration range for the saturated media mix 1 column and the saturated media mix 2 column.

Table 36: Influent Orthophosphate Concentrations for Saturated Media Mix 1 and Media Mix 2

Media	Approximate Total System Influent Orthophosphate Concentration (mg/L as PO_4-P)	Range of Influent Orthophosphate Concentrations for Saturated Columns (mg/L as PO_4-P)
1	0.125	0.127-0.137
2	0.125	0.116-0.194
1	0.361	0.144-0.157
2	0.361	0.094-.0131
1	0.785	0.155-0.195
2	0.785	0.130-0.284

Figures 27-29 present data from column test experimentation where the y and x-axis are defined in terms of (C/C_0) and time in hours. In Figures 27-29 Orthophosphate removal for the saturated columns given system Orthophosphate influent concentrations of 0.125, 0.361 and 0.785 mg/L PO_4-P are shown.

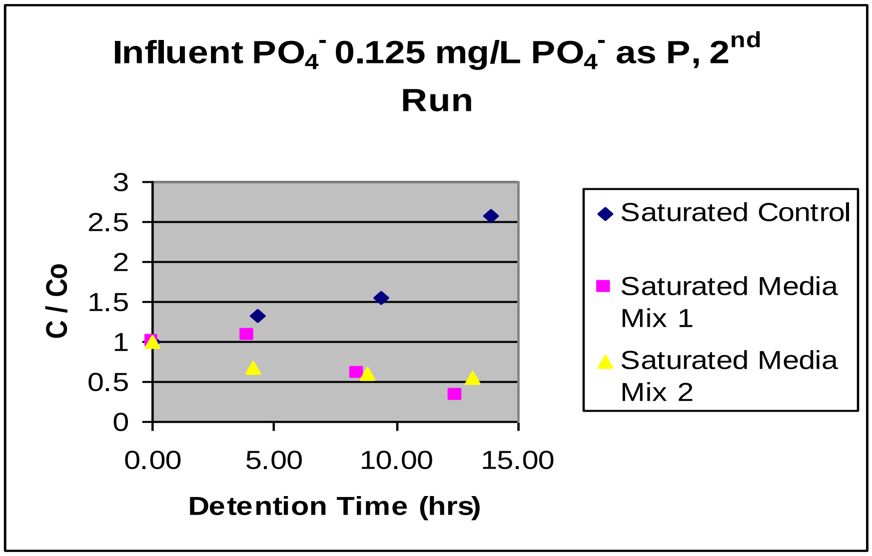

Figure 27: Nitrate Removal for Saturated Columns given 0.125 mg/L PO4-P influent

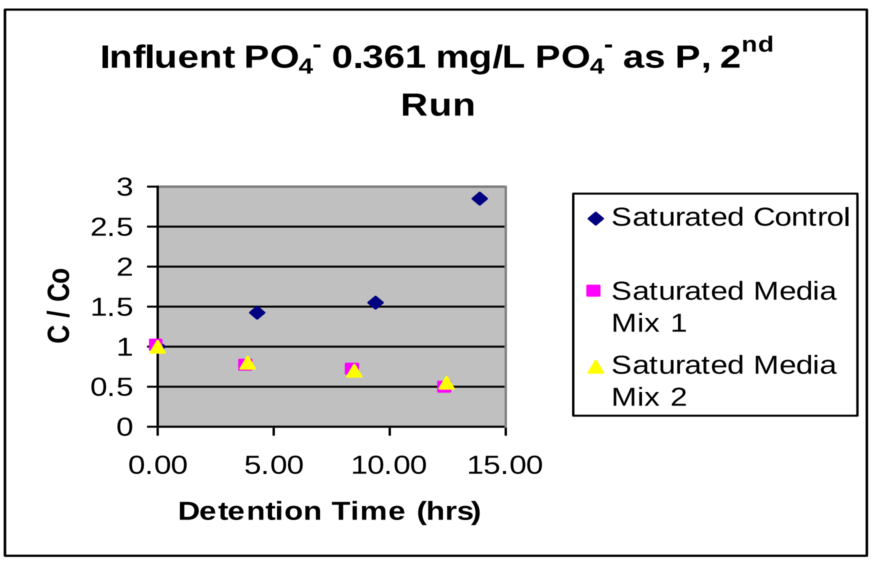

Figure 28: Nitrate Removal for Saturated Columns given 0.361 mg/L PO4-P influent

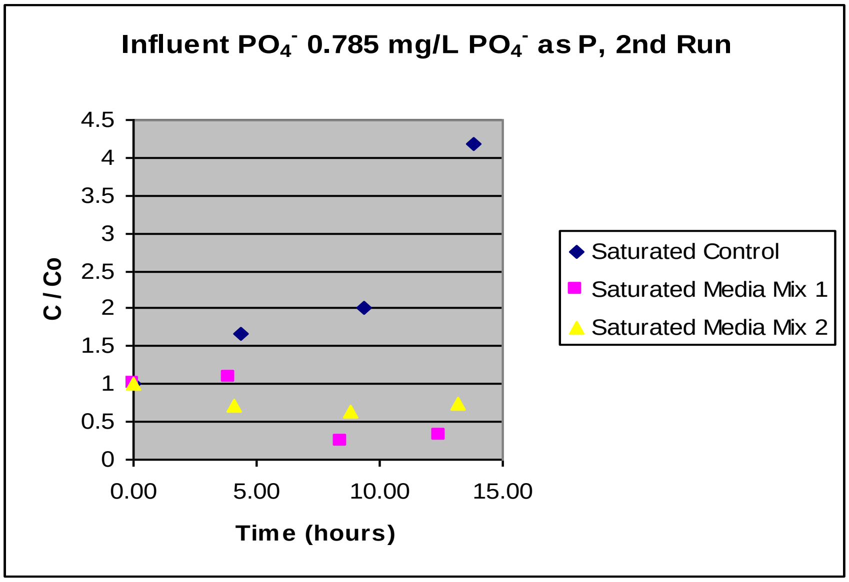

Figure 29: Nitrate Removal for Saturated Columns given 0.785 mg/L PO4-P influent

For the saturated control Figures 27-29 show a gradual initial increase in Orthophosphate followed by a rapid increase. Shown in Figures 27-29 saturated media mixes 1 and 2 gradually removal Orthophosphate. Orthophosphate concentrations steadily decrease as the augmented stormwater passes through the saturated media mix columns.

Saturated Total Phosphorus Reduction

Total Phosphorus TP removal for the saturated columns varied for each influent Orthophosphate concentration. For influent Orthophosphate concentration 0.125 mg/L PO_4—P the average removal for the saturated control, media mix 1 and media mix 2 was shown in Table

37 to be approximately -185%, 81 % and 86%. The negative removal efficiency for the saturated control indicates TP addition of 185%. Shown in Table 38 the TP removal efficiency for Orthophosphate system influent of concentration 0.361 mg/L PO_4-P. For the saturated control the average TP addition decreases from 185% to 105%. The average TP removal efficiency for media 1 mix increases to approximately 86% and the average TP removal efficiency for media mix 2 decreases from 86% to 72%. Shown in Table 39 for influent Orthophosphate concentration of 0.785 mg/L PO_4-P, media mix 1 and media mix 2 average TP removals of approximately 85% and 63%. At this influent Orthophosphate concentration the saturated control adds an average of 144.5% of TP. The results indicate both media mix 1 and media mix 2 are effective in reducing TP given influent Orthophosphate of concentration 0.125, 0.361 and 0.785 mg/L PO_4-P.

Table 37: Total Phosphorus Removal Efficiency for Saturated Columns Given System Influent Orthophosphate Concentration 0.125 mg/L PO4-P

Control Run	Initial Concentration (mg/L as P) Top Column 2	Final Concentration (mg/L as P) Bottom Column 2	Removal Efficiency (%)
1	0.078	0.156	-100.1
2	0.058	0.233	-304.6
3	0.110	0.274	-149.6
Average	0.082	0.221	-184.8
Media 1 Run	Initial Concentration (mg/L as P) Top Column 4	Final Concentration (mg/L as P) Bottom Column 4	Removal Efficiency (%)
1	0.451	0.067	85.1
2	0.416	0.098	76.4
3	0.605	0.114	81.2
Average	0.491	0.093	80.9
Media 2 Run	Initial Concentration (mg/L as P) Top Column 6	Final Concentration (mg/L as P) Bottom Column 6	Removal Efficiency (%)
1	0.752	0.048	93.6
2	0.266	0.075	71.9
3	1.305	0.085	93.4
Average	0.774	0.069	86.3

Table 38: Total Phosphorus Removal Efficiency for Saturated Columns Given System Influent Orthophosphate Concentration 0.361 mg/L PO4-P

Control Run	Initial Concentration (mg/L as P) Top Column 2	Final Concentration (mg/L as P) Bottom Column 2	Removal Efficiency (%)
1	1.035	0.224	78.4
2	0.073	0.238	-226.5
3	0.091	0.243	-165.7
Average	0.400	0.235	-104.6
Media 1 Run	Initial Concentration (mg/L as P) Top Column 4	Final Concentration (mg/L as P) Bottom Column 4	Removal Efficiency (%)
1	0.927	0.154	83.3
2	0.959	0.105	89.0
3	0.877	0.114	87.0
Average	0.921	0.125	86.5
Media 2 Run	Initial Concentration (mg/L as P) Top Column 6	Final Concentration (mg/L as P) Bottom Column 6	Removal Efficiency (%)
1	0.703	0.080	88.7
2	0.310	0.097	68.6
3	0.367	0.147	60.0
Average	0.460	0.108	72.4

Table 39: Total Phosphorus Removal Efficiency for Saturated Columns Given System Influent Orthophosphate Concentration 0.785 mg/L PO4-P

Control Run	Initial Concentration (mg/L as P) Top Column 2	Final Concentration (mg/L as P) Bottom Column 2	Removal Efficiency (%)
1	1.265	0.261	79.4
2	0.082	0.293	-256.4
3	0.082	0.293	-256.4
Average	0.477	0.282	-144.5
Media 1 Run	Initial Concentration (mg/L as P) Top Column 4	Final Concentration (mg/L as P) Bottom Column 4	Removal Efficiency (%)
1	1.496	0.125	91.6
2	0.779	0.146	81.2
3	0.779	0.146	81.2
Average	1.018	0.139	84.7
Media 2 Run	Initial Concentration (mg/L as P) Top Column 6	Final Concentration (mg/L as P) Bottom Column 6	Removal Efficiency (%)
1	0.334	0.083	75.1
2	0.222	0.096	56.9
3	0.222	0.096	56.9
Average	0.259	0.091	62.9

Column pH

Depending on location and water quality, pH may be an important consideration in determining the optimal stormwater media mix. The average pH profile in saturated columns for influent Nitrate concentrations of 0.38, 1.26 and 2.53 mg/L NO_3-N are shown in Figures 30-32. To test pH effects of media, the saturated control, saturated media 1 and saturated media 2 are examined. For all influent Nitrate concentrations in Figures 30-32 the average pH profile was fairly consistent. The values of pH for the saturated control and saturated media 1 tended to decrease with time spent in each column. Saturated media 2 consistently elevated pH to approximately 7.6. The crushed limestone in media 2 is responsible for the elevated pH in media 2. Increased acidity in natural ecosystems from acid rain or poorly buffered receiving bodies may require pH sensitive stormwater solutions. Media 2 would give stormwater engineers and designers the ability to add pH to treated stormwater thus potentially lessening the impact of stormwater of receiving bodies.

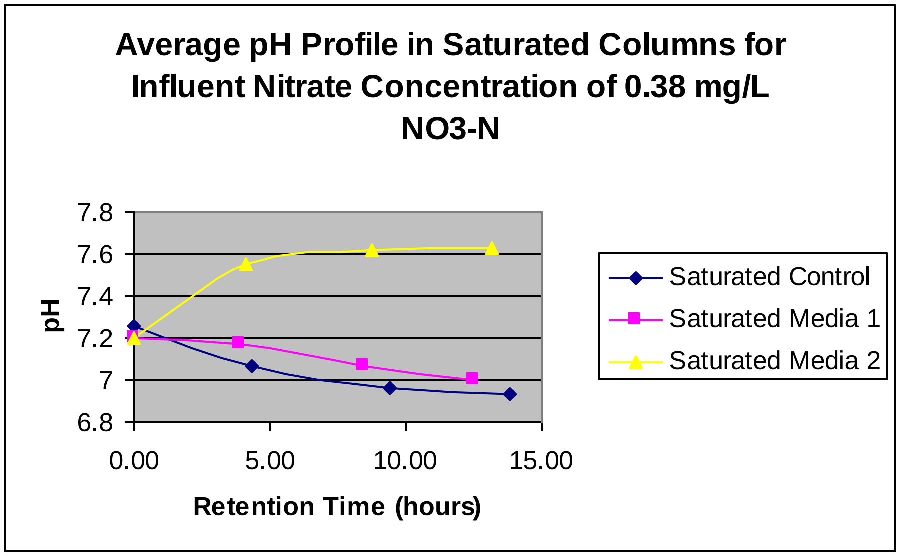

Figure 30: Average (n=3) pH Profile for Influent Nitrate Concentration of 0.38 mg/L NO3-N

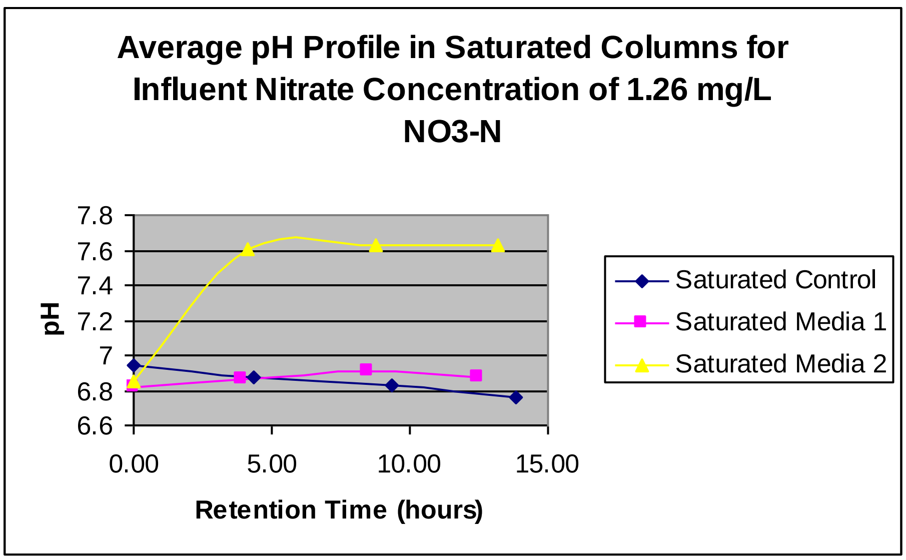

Figure 31: Average (n=3) pH Profile for Influent Nitrate Concentration of 1.26 mg/L NO3-N

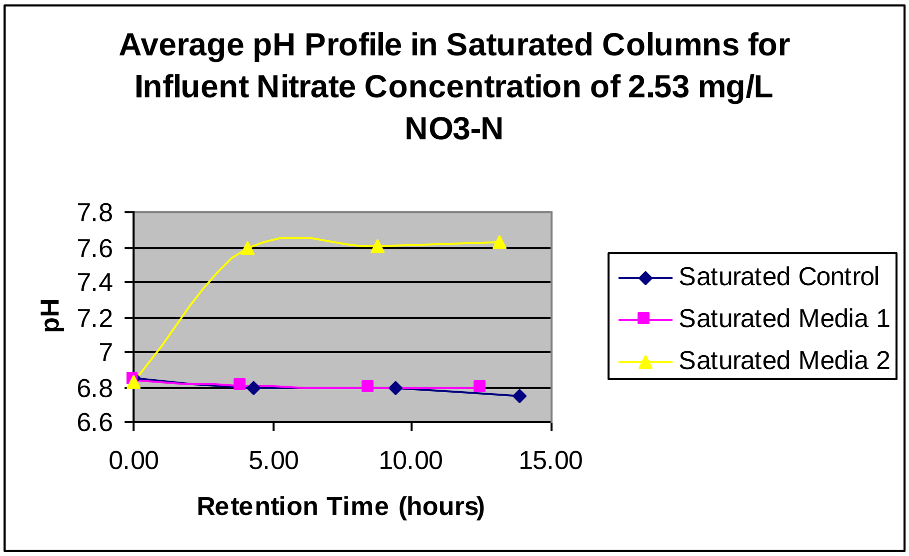

Figure 32: Average (n=3) pH Profile for Influent Nitrate Concentration of 2.53 mg/L NO3-N

CHAPTER FIVE: SUMMARY, CONCLUSION, RECOMMENDATIONS

Summary

Surface water and ground water are decreasing in quantity and quality. Nutrient rich stormwater runoff contributes to decreased surface water and ground water quality by carrying Nitrate and Phosphorus into receiving bodies such as rivers, lakes and streams. Nitrate rich stormwater runoff may percolate into groundwater thus increasing Nitrate concentrations within groundwater.

Stormwater can contain nutrients that may contaminate surface waters and ground water. To minimize the impact of nutrient loading on surface waters and ground water, potential filter media are thoroughly researched. A team of UCF researchers conducted an intensive literature reviewed that indicated 32 different types of media may be used to reduce Nitrogen and or Phosphorus within stormwater runoff. Each potential media was qualitatively then quantitative evaluated based on 5 criteria: 1) relevance, 2) permeability, 3) cost, 4) availability in Florida, and 5) additional environmental benefit. Based on quantitative evaluation of the 5 selection criteria, the 7 top performing media were selected for batch test experimentation. The seven media selected for batch experimentation were: Florida peat, sandy loam, woodchips, crushed oyster shell, crushed limestone, tire crumb and sawdust. The selected media mixes must have the ability to remove both Nitrogen and Phosphorus.

Batch test experimentation could not quantify Nitrate removal because the necessary anaerobic conditions were not available during batch test experimentation. Therefore potential filter media mixes were selected based on their ability to remove Orthophosphate and Ammonia Nitrogen at a retention time of 48 hours. Based on the results of the batch test, 2 media mixes were selected: media mix 1: 50% sand, 30% tire crumb, 20% sawdust by weight and media mix 2: 50% sand, 25% sawdust, 15% tire crumb, 10% limestone by weight. After the media mixes were defined the physical properties of the media mixes are found in the materials characterization section. The density, void ratio, porosity, specific gravity, surface area and permeability were found for media mix 1, media mix 2 and the control soil from Hunter's Trace.

Laboratory columns were created to model a dry detention pond and emulate actual subsurface conditions in a controlled environment. The first column simulates a path through the semi-dry vadose zone and the second column simulates a saturated anaerobic environment. The objective of column test experimentation is to quantify nutrient removal potential of the control, media mix 1 and media mix 2 within a saturated anaerobic environment. The goal of the experimentation as a whole is to bring Nitrate and Phosphorus reduction from concept to execution via literature search, batch test experimentation and column test experimentation.

Conclusion

In column test experimentation media mixes 1 and 2 consistently outperformed the control with respect to Nitrate removal efficiency. Media mixes 1 and 2 had Nitrate removal efficiencies ranging from 60% to 99%. The control Nitrate removal efficiencies ranges from 38%-80%. With respect to Nitrate removal efficiency media mix 1 slightly outperformed media mix 2 in all of the tested Nitrate concentrations. For media mixes 1 and 2 Nitrate removal efficiency increases as influent Nitrate concentration increases. For the control, Nitrate removal efficiency decreases as influent Nitrate concentration increases. Throughout the tested concentration range media mix 1 and media mix 2 where effective in reducing Nitrate within the saturated columns. The Nitrate removal performance of media mix 1 and media mix 2 cannot be directly compared because of differing saturated influent Nitrate concentrations.

Total Nitrogen (TN) removal for media mixes 1 and 2 varied from 169% TN addition to 89% TN reduction. For media mixes 1 and 2 TN removal efficiencies increased as influent Nitrate increased. The TN within the column system is in mainly two forms: Nitrate Nitrogen and Ammonia Nitrogen. Media mix 1 and media mix 2 add Ammonia Nitrogen to the water. As the Nitrate concentration increases, it becomes a greater percentage of the TN. Media mixes 1 and 2 are highly effective at removing Nitrate from water, therefore as Nitrate increases TN removal increases. Unlike media mixes 1 and 2 the control showed no definitive trend relating TN removal efficiency to influent Nitrate concentration. For TN reduction media mix 1 and media mix 2 may not be considered effective because of TN addition given influent Nitrate concentrations 0.38 and 1.26 mg/L NO_3-N. Based on the differing influent saturated Nitrate concentrations TN removal performance for media mix 1 and media mix 2 cannot be directly compared.

Over all influent Orthophosphate concentrations tested media 1 and media 2 consistently outperform the control. For media mix 1 and media mix 2 average Orthophosphate removal efficiency ranges from approximately 42% to 67%. For every run in every influent Orthophosphate concentration the saturated control adds Orthophosphate to the water. There is no concrete relationship between influent Orthophosphate concentration and Orthophosphate removal efficiency. The saturated influent Orthophosphate values tend to vary despite an increased system influent Orthophosphate concentration. Media mix 1 consistently outperforms media mix 2 with respect to Orthophosphate removal efficiency. In the tested Orthophosphate concentrations, on average media mix 1 removes approximately 10%-20% more Orthophosphate than media mix 2, however media mix 1 had higher influent saturated Orthophosphate concentrations than media mix 2. Therefore direct comparison of Orthophosphate removal efficiencies couls not be accomplished.

Orthophosphate removal unlike Nitrate removal takes place throughout the entire saturated column. Orthophosphate influent values were also typically higher for media mix 1 than media mix 2. The higher influent Orthophosphate concentrations for media mix 1 maybe the reason for increased Orthophosphate removal with respect to Orthophosphate removals for media mix 2.

Total Phosphorus TP removal for the saturated columns varied for each influent Orthophosphate concentration. Throughout the tested range in influent Orthophosphate concentrations media mix 1 and media mix 2 outperformed the control with respect to TP removal efficiency. The saturated control consistently added TP to the system. Media mix 1 and media mix 2 reduced TP on average from approximately 63% to 86%. Media mix 1 showed greater average consistency in TP removal compared to media mix 2. Considering all influent Orthophosphate concentrations, average TP removal efficiencies for media mix 1 ranged from approximately 81% to 86%. Media mix 2 averaged TP removal efficiency of between 63% and 86%.

The pH values for media mix 1 and media mix 2 were markedly different. The augmented stormwater treated by media mix 2 had consistently higher pH values than water treated by media mix 1 and the control. Water treated with media mix 1 had slightly greater pH values than water treated by the control. The increased pH value of media mix 2 may be necessary if stormwater is discharged into poorly buffered receiving bodies. If higher effluent pH values are required then media mix 2 should be selected for use in stormwater treatment.

Dissolved oxygen measurements within the experiment suggest that the anaerobic conditions required for bacterial denitrification are present within the saturated columns. Dissolved oxygen concentrations in the saturated columns are near zero aside from interference caused by air bubbles entering the testing apparatus. Low DO observations contributing to an anaerobic environment are consistent with the Nitrate removal/ denitrification that is taking place within the saturated columns.

Recommendations

Based on TN addition resulting from influent Nitrate concentrations of 0.38 and 1.26 mg/L NO_3-N media mix 1 should not be considered for application if stormwater Nitrate concentrations are equal to or less than 0.38 mg/L NO_3-N. Media mix 2 should not be considered for application if stormwater Nitrate concentrations are equal to or less than 1.26 mg/L NO_3-N. Media mixes 1 and 2 should be considered for removal of Nitrate given influent Nitrate concentration of approximately 2.53 mg/L NO_3-N. Media mixes 1 and 2 should also be considered for Orthophosphate reduction in stormwater given influent Orthophosphate concentrations of 0.125, 0.361 and 0.785 mg/L PO_4-P. Given a 4 hour detention time under the experimental conditions media mix 1 and media mix 2 are able to achieve the stated removals for

Nitrate and Orthophosphate. If pH adjustment to a higher value is beneficial, media mix 2 with limestone is better.

The use of sawdust may reduce Total Nitrogen output of the system. Sawdust is an electron donor which is required by the media mixes to facilitate denitrification, however sawdust contributes substantial Ammonia to the water. Finding the optimal amount of sawdust for media mixes would lower the amount of Ammonia added and keep Nitrate removal efficiencies relatively high. Optimizing sawdust within media mixes would lower Ammonia and therefore lower effluent TN.

Within this experiment most of the Nitrate removal took place within the first 4 hours of retention time. This observation is consistent with other studies that suggest most denitrification takes place within a 2 hour retention time (Environmental Operating Solutions, 2008).

Throughout experimentation the control, media mix 1 and media mix 2 could not be directly compared because of differing nutrient concentrations input to the saturated zones. Consistently saturated influent Nitrate concentrations and saturated influent Orthophosphate concentrations were different entering the saturated column for the control, media mix 1 and media mix 2. Different influent saturated nutrient concentrations were the result of nutrient removal performance variability in the unsaturated control columns. For direct control and media mix comparison, known nutrient concentrations should be input directly into the saturated zone.

In the future, experimentation should be done to quantify the optimal quantity of electron donor to reduce Ammonia and Total Nitrogen input. The hydraulic conductivity of the media mixes is greater than the control; therefore the unsaturated-saturated system is limited to the maximum flow rate of the unsaturated column. Experimenting only with the saturated column would allow for direct nutrient input and therefore direct comparison of removal efficiencies for the media mixes and the control. For future experimentation it is recommended that the sawdust and limestone within the media mix be decreased. Thus, it is recommended that testing a media mix consisting of 5% sawdust and 5% limestone by weight be done. The decreased sawdust may provide for decreased ammonia leaching from the media mixes. The nitrate removal effectiveness of the 5% sawdust media mix by weight may be compared to the results of the experiment which used 20% and 25% sawdust by weight to identify a potential relationship between electron donor quantity and nitrate removal effectiveness. Adding 5% limestone by weight may help buffer the effluent which may be desirable in areas of acid rain where effluent pH may be of concern. Throughout the duration of the experiment the temperature was fairly constant. Other interesting topics that may be pursued as an extension of this work are the Phosphorus sorption capacity of the media mixes and the estimated lifespan of sawdust as an electron donor.

APPENDIX A: QA/QC

Table 1A: QA/QC for Nitrate + Nitrite

DATE	Location	Conc. (mg/L as NO_3-N)	Dup. Conc. (mg/L as NO_3-N)	RPD (%)		Conc. (mg/L as NO_3-N)	Dup. Conc. (mg/L as NO_3-N)	Recovery (%)
3/26/08	Media 1/port3	0.0197	0.0205	4		0.0197	0.2877	107
3/26/08	Media 2/port3	0.0216	0.0228	5		0.0216	0.2546	93
3/27/08	Media 1/port2	0.0232	0.0220	5		0.0232	0.2999	111
3/27/08	Media 2/port2	0.0232	0.0236	2		0.0232	0.2346	85
3/28/08	Media 1/port2	0.0236	0.0224	5		0.0236	0.2675	98
3/28/08	Media 2/port2	0.0240	0.0240	0		0.0240	0.2135	76
3/31/08	Media 1/port2	0.0276	0.0248	11		0.0276	0.2099	73
3/31/08	Media 2/port2	0.0288	0.0280	3		0.0288	0.2877	104
4/1/08	Media 1/port2	0.0220	0.0216	2		0.0220	0.3088	115
4/1/08	Media 2/port2	0.0232	0.0236	2		0.0232	0.2950	109
4/2/08	Media 1/port2	0.0232	0.0220	5		0.0232	0.2132	76
4/2/08	Media 2/port2	0.0244	0.0260	6		0.0244	0.2799	102
4/7/08	Media 1/port2	0.02	0.02	3		0.0236	0.3188	118
4/7/08	Media 2/port2	0.02	0.02	3		0.0240	0.2121	75
4/8/08	Media 1/port2	0.02	0.02	10		0.0248	0.2256	80
4/8/08	Media 2/port2	0.02	0.03	3		0.0244	0.2347	84
4/9/08	Media 1/port2	0.03	0.04	12		0.0320	0.3266	118
4/9/08	Media 2/port2	0.02	0.02	0		0.0210	0.2968	110

Table 2A: QA/QC for TN

DATE	Location	Conc. (mg/L as N)	Dup. Conc. (mg/L as N)	RPD (%)	Conc. (mg/L as N)	Dup. Conc. (mg/L as N)	Recovery (%)
3/26/08	Media 1/port3	1.32701	1.25435	6	1.32701	1.8534	105
3/26/08	Media 2/port3	1.276855	1.14876	11	1.276855	1.8345	112
3/27/08	Media 1/port2	1.2267	1.34657	9	1.2267	1.7567	106
3/27/08	Media 2/port2	0.62484	0.86785	33	0.62484	1.0374	83
3/28/08	Media 1/port2	1.02608	1.14325	11	1.02608	1.6876	132
3/28/08	Media 2/port2	0.62484	0.765678	20	0.62484	1.1046	96
3/31/08	Media 1/port2	0.975925	1.1354	15	0.975925	1.5099	107
3/31/08	Media 2/port2	0.62484	0.7598756	20	0.62484	1.0126	78
4/1/08	Media 1/port2	1.276855	1.20435	6	1.276855	1.8246	110
4/1/08	Media 2/port2	0.62484	0.9453	41	0.62484	1.1035	96
4/2/08	Media 1/port2	1.2267	1.34521	9	1.2267	1.8097	117
4/2/08	Media 2/port2	0.574685	0.554876	4	0.574685	1.1083	107
4/7/08	Media 1/port2	0.875615	0.804534	8	0.875615	1.3987	105
4/7/08	Media 2/port2	0.2236	0.20655	8	0.2236	0.6999	95
4/8/08	Media 1/port2	0.474375	0.405676	16	0.474375	1.0023	106
4/8/08	Media 2/port2	0.32391	0.305467	6	0.32391	0.9077	117
4/9/08	Media 1/port2	0.42422	0.40787857	4	0.42422	0.9068	97
4/9/08	Media 2/port2	0.2236	0.25678	14	0.2236	0.7567	107

Table 3A: QA/QC for Ammonia

DATE	Location	Conc. (mg/L as P)	Dup. Conc. (mg/L as NH_3-N)	RPD (%)	Conc. (mg/L as NH_3-N)	Dup. Conc. (mg/L as NH_3-N)	Recovery (%)
3/26/2008	**Media 1/port3**	0.0743	0.0677	9	0.0743	0.1813	107
3/26/2008	**Media 2/port3**	0.0934	0.0743	23	0.0934	0.1734	80
3/27/2008	**Media 1/port2**	0.0172	0.0213	21	0.0172	0.1192	102
3/27/2008	**Media 2/port2**	0.0543	0.0482	12	0.0543	0.1829	129
3/28/2008	**Media 1/port2**	0.047	0.0514	9	0.047	0.155	108
3/28/2008	**Media 2/port2**	0.0914	0.0893	2	0.0914	0.2114	120
3/31/2008	**Media 1/port2**	0.0205	0.018	13	0.0205	0.1105	90
3/31/2008	**Media 2/port2**	0.016	0.0148	8	0.016	0.1066	91
4/1/2008	**Media 1/port2**	0.0616	0.0592	4	0.0616	0.1416	80
4/1/2008	**Media 2/port2**	0.0791	0.073	8	0.0791	0.1631	84
4/2/2008	**Media 1/port2**	0.0661	0.0612	8	0.0661	0.1516	86
4/2/2008	**Media 2/port2**	0.0193	0.0221	14	0.0193	0.1253	106
4/7/2008	**Media 1/port2**	0.051	0.0482	6	0.051	0.161	110
4/7/2008	**Media 2/port2**	0.0518	0.0494	5	0.0518	0.1598	108
4/8/2008	**Media 1/port2**	0.0612	0.0563	8	0.0612	0.1571	96
4/8/2008	**Media 2/port2**	0.0083	0.0062	28	0.0083	0.1173	109
4/9/2008	**Media 1/port2**	0.0539	0.0482	11	0.0539	0.1679	114
4/9/2008	**Media 2/port2**	0.0384	0.0343	11	0.0384	0.1244	86

Table 4A: QA/QC for Nitrite

DATE	Location	Conc. (mg/L as P)	Dup. Conc. (mg/L NO_2^- as N)	RPD (%)
3/26/08	**Media 1/port3**	0.0157	0.0177	12
3/26/08	**Media 2/port3**	0.0197	0.0201	2
3/27/08	**Media 1/port2**	0.0157	0.0165	5
3/27/08	**Media 2/port2**	0.0177	0.0185	4
3/28/08	**Media 1/port2**	0.0177	0.0161	9
3/28/08	**Media 2/port2**	0.0161	0.0169	5
3/31/08	**Media 1/port2**	0.0177	0.0201	13
3/31/08	**Media 2/port2**	0.0185	0.0209	12
4/1/08	**Media 1/port2**	0.0185	0.0177	4
4/1/08	**Media 2/port2**	0.0165	0.0181	9
4/2/08	**Media 1/port2**	0.0185	0.0197	6
4/2/08	**Media 2/port2**	0.0197	0.0185	6
4/7/08	**Media 1/port2**	0.0177	0.0161	9
4/7/08	**Media 2/port2**	0.0193	0.0189	2
4/8/08	**Media 1/port2**	0.0177	0.0169	5
4/8/08	**Media 2/port2**	0.0189	0.0161	16
4/9/08	**Media 1/port2**	0.0181	0.0181	0
4/9/08	**Media 2/port2**	0.0193	0.0224	15

Table 5A: QA/QC for Orthophosphate

DATE	Location	Conc. (mg/L as PO_4-P)	Dup. Conc. (mg/L as PO_4-P)	RPD (%)	Conc. (mg/L as PO_4-P)	Dup. Conc. (mg/L as PO_4-P)	Recovery (%)
4/22/2008	**Media 1/port2**	0.109	0.107	2	0.109	0.327	87.024
4/22/2008	**Media 2/port2**	0.122	0.112	9	0.122	0.339	86.572
4/23/2008	**Media 1/port2**	0.147	0.134	9	0.147	0.437	115.812
4/23/2008	**Media 2/port2**	0.091	0.084	7	0.091	0.36	107.568
4/24/2008	**Media 1/port2**	0.036	0.043	17	0.036	0.328	116.612
4/24/2008	**Media 2/port2**	0.083	0.088	6	0.083	0.346	105.047
4/28/2008	**Media 1/port2**	0.087	0.095	9	0.087	0.279	76.692
4/28/2008	**Media 2/port2**	0.103	0.114	11	0.103	0.35	98.925
4/29/2008	**Media 1/port2**	0.118	0.101	15	0.118	0.388	107.726
4/29/2008	**Media 2/port2**	0.104	0.108	4	0.104	0.399	117.911
4/30/2008	**Media 1/port2**	0.054	0.064	15	0.054	0.257	80.986
4/30/2008	**Media 2/port2**	0.074	0.071	4	0.074	0.368	117.559
5/7/2008	**Media 1/port2**	0.092	0.087	6	0.092	0.388	118.126
5/7/2008	**Media 2/port2**	0.1	0.123	21	0.1	0.364	105.534
5/8/2008	**Media 1/port2**	0.129	0.11	16	0.129	0.357	91.268
5/8/2008	**Media 2/port2**	0.102	0.139	30	0.102	0.32	87.117
5/9/2008	**Media 1/port2**	0.129	0.113	13	0.129	0.396	106.731
5/9/2008	**Media 2/port2**	0.102	0.117	13	0.102	0.397	118.153

Table 6A: QA/QC for Total Phosphorus

DATE	Location	Conc. (mg/L as P)	Dup. Conc. (mg/L as P)	RPD (%)	Conc. (mg/L as P)	Dup. Conc. (mg/L as P)	Recovery (%)
4/22/2008	**Media 1/port2**	0.054	0.067	22	0.054	0.122	104.383
4/22/2008	**Media 2/port2**	0.066	0.07	6	0.066	0.14	113.639
4/23/2008	**Media 1/port2**	0.06	0.071	17	0.06	0.119	89.882
4/23/2008	**Media 2/port2**	0.054	0.05	7	0.054	0.11	86.13
4/24/2008	**Media 1/port2**	0.094	0.105	11	0.094	0.143	75.289
4/24/2008	**Media 2/port2**	0.092	0.09	3	0.092	0.16	103.412
4/28/2008	**Media 1/port2**	0.108	0.13	19	0.108	0.197	136.909
4/28/2008	**Media 2/port2**	0.085	0.097	13	0.085	0.165	123.278
4/29/2008	**Media 1/port2**	0.061	0.05	20	0.061	0.125	97.234
4/29/2008	**Media 2/port2**	0.056	0.06	6	0.056	0.119	95.654
4/30/2008	**Media 1/port2**	0.078	0.09	14	0.078	0.134	86.023
4/30/2008	**Media 2/port2**	0.077	0.066	16	0.077	0.126	74.726
5/7/2008	**Media 1/port2**	0.092	0.104	12	0.092	0.16	103.577
5/7/2008	**Media 2/port2**	0.1	0.13	25	0.1	0.19	136.807
5/8/2008	**Media 1/port2**	0.129	0.131	2	0.129	0.202	112.047
5/8/2008	**Media 2/port2**	0.102	0.13	24	0.102	0.176	112.908
5/9/2008	**Media 1/port2**	0.129	0.14	8	0.129	0.19	93.642
5/9/2008	**Media 2/port2**	0.102	0.113	10	0.102	0.165	96.481

Table 7A: QA/QC for pH

DATE	Location	pH	Duplicate pH	RPD (%)
3/26/08	reservoir	7.4	7.34	1
3/27/08	reservoir	7.42	7.36	1
3/28/08	reservoir	7.39	7.3	1
3/31/08	reservoir	7.1	7.2	1
4/1/08	reservoir	7.15	7.3	2
4/2/08	reservoir	7.13	7.15	0
4/7/08	reservoir	7.1	7.15	1
4/8/08	reservoir	7.13	7.08	1
4/9/08	reservoir	7.09	7.18	1
4/22/08	reservoir	7.21	7.3	1
4/23/08	reservoir	7.17	7.25	1
4/24/08	reservoir	7.23	7.32	1
4/28/08	reservoir	7.34	7.29	1
4/29/08	reservoir	7.3	7.24	1
4/30/08	reservoir	7.33	7.38	1
5/7/08	reservoir	7.05	7.2	2
5/8/08	reservoir	7.1	7.14	1
5/9/08	reservoir	7.08	7.15	1

Table 8A: QA/QC for DO

DATE	Location	DO	Duplicate DO	RPD (%)
3/28/08	reservoir	2.56	2.51	2
3/28/08	Bottom of Saturated Control Column	0.14	0.18	25
4/2/08	reservoir	2.46	2.43	1
4/2/08	Bottom of Saturated Control Column	0.21	0.24	13
4/9/08	reservoir	3.01	2.95	2
4/9/08	Bottom of Saturated Control Column	0.09	0.13	36

APPENDIX B: RAW DATA

Table 1B: Nitrate + Nitrite for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 1st Run, 3/26/08

1st run **3/26/2008**

Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	0.55622	saturated port 1	0	0.3826	saturated port 1	0	0.229
saturated port 3	9.383333	0.85554	saturated port 3	8.45	0.0197	saturated port 3	8.7746	0.022
bottom of saturated	13.85	0.29407	bottom of saturated	12.46667	0.0209	bottom of saturated	13.16667	0.022

Table 2B: Nitrate + Nitrite for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 2nd Run, 3/27/08

2nd run **3/27/2008**

Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	0.63	saturated port 1	0	0.358	saturated port 1	0	0.14
saturated port 2	4.333333	0.86	saturated port 2	3.9	0.023	saturated port 2	4.116667	0.02
saturated port 3	9.383333	0.87	saturated port 3	8.45	0.022	saturated port 3	8.7746	0.02
bottom of saturated	13.85	0.27	bottom of saturated	12.46667	0.022	bottom of saturated	13.16667	0.02

Table 3B: Nitrate + Nitrite for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 3rd Run, 3/28/08

3rd run **3/28/2008**

Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	0.687	saturated port 1	0	0.344	saturated port 1	0	0.058
saturated port 2	4.333333	0.807	saturated port 2	3.9	0.024	saturated port 2	4.116667	0.024
saturated port 3	9.383333	0.82	saturated port 3	8.45	0.023	saturated port 3	8.7746	0.023
bottom of saturated	13.85	0.139	bottom of saturated	12.46667	0.023	bottom of saturated	13.16667	0.023

Table 4B: Nitrate + Nitrite for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 1st Run, 3/31/08

1st run	**3/31/2008**							
Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	1.534	saturated port 1	0	0.612	saturated port 1	0	0.216
saturated port 2	4.333333	1.553	saturated port 2	3.9	0.028	saturated port 2	4.116667	0.029
saturated port 3	9.383333	1.031	saturated port 3	8.45	0.021	saturated port 3	8.7746	0.025
bottom of saturated	13.85	0.312	bottom of saturated	12.46667	0.023	bottom of saturated	13.16667	0.025

Table 5B: Nitrate + Nitrite for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 2nd Run, 4/1/08

2nd run	**4/1/2008**							
Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	1.888	saturated port 1	0	1.033	saturated port 1	0	0.312
saturated port 2	4.333333	1.462	saturated port 2	3.9	0.022	saturated port 2	4.116667	0.024
saturated port 3	9.383333	1.417	saturated port 3	8.45	0.022	saturated port 3	8.7746	0.026
bottom of saturated	13.85	0.391	bottom of saturated	12.46667	0.022	bottom of saturated	13.16667	0.023

Table 6B: Nitrate + Nitrite for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 3rd Run, 4/2/08

3rd run	**4/2/2008**							
Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	2.184	saturated port 1	0	1.118	saturated port 1	0	0.276
saturated port 2	4.333333	1.848	saturated port 2	3.9	0.023	saturated port 2	4.116667	0.024
saturated port 3	9.383333	1.51	saturated port 3	8.45	0.023	saturated port 3	8.7746	0.025
bottom of saturated	13.85	0.438	bottom of saturated	12.46667	0.023	bottom of saturated	13.16667	0.024

Table 7B: Nitrate + Nitrite for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 1st Run, 4/7/08

1st run	**4/7/2008**							
Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	2.605	saturated port 1	0	1.945	saturated port 1	0	0.781
saturated port 2	4.333333	2.845	saturated port 2	3.9	0.024	saturated port 2	4.116667	0.024
saturated port 3	9.383333	2.391	saturated port 3	8.45	0.024	saturated port 3	8.7746	0.026
bottom of saturated	13.85	1.615	bottom of saturated	12.46667	0.021	bottom of saturated	13.16667	0.024

Table 8B: Nitrate + Nitrite for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 2nd Run, 4/8/08

2nd run	**4/8/2008**							
Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	2.524	saturated port 1	0	1.976	saturated port 1	0	0.817
saturated port 2	4.333333	2.836	saturated port 2	3.9	0.025	saturated port 2	4.116667	0.024
saturated port 3	9.383333	2.27	saturated port 3	8.45	0.022	saturated port 3	8.7746	0.024
bottom of saturated	13.85	1.508	bottom of saturated	12.46667	0.021	bottom of saturated	13.16667	0.022

Table 9B: Nitrate + Nitrite for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 3rd Run, 4/9/08

3rd run	**4/9/2008**							
Control Column			Media 1			Media 2		
Nitrate			Nitrate			Nitrate		
Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_3^- as N)
saturated port 1	0	2.449	saturated port 1	0	1.954	saturated port 1	0	0.795
saturated port 2	4.333333	2.823	saturated port 2	3.9	0.024	saturated port 2	4.116667	0.025
saturated port 3	9.383333	2.212	saturated port 3	8.45	0.022	saturated port 3	8.7746	0.024
bottom of saturated	13.85	1.463	bottom of saturated	12.46667	0.021	bottom of saturated	13.16667	0.022

Table 10B: Nitrate + Nitrite, TN, Ammonia and Nitrite in Reservoir

Date	Reservoir Nitrate Concentration mg/L NO_3-N	Reservoir TN Concentration mg/L as N	Reservoir Ammonia Concentration mg/L NH_3^+ - N	Reservoir Nitrite Concentration mg/L NO_2^--N
3/26/2008	0.38	1.33	0.01	0.02
3/27/2008	0.38	1.33	0.01	0.02
3/28/2008	0.38	1.33	0.01	0.02
3/31/2008	1.26	1.82	0.03	0.05
4/1/2008	1.26	1.82	0.03	0.05
4/2/2008	1.26	1.82	0.03	0.05
4/7/2008	2.53	2.18	0.04	0.04
4/8/2008	2.53	2.18	0.04	0.04
4/9/2008	2.53	2.18	0.04	0.04

Table 11B: TN for Influent Nitrate Concentration of 0.38 mg/L N, 1st Run, 3/26/08

1st run **3/26/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	1.427	saturated port 1	0	0.976	saturated port 1	0	0.474
saturated port 3	9.383333	9.201	saturated port 3	8.45	1.227	saturated port 3	8.7746	0.725
bottom of saturated	13.85	0.976	bottom of saturated	12.46667	1.327	bottom of saturated	13.16667	1.277

Table 12B: TN for Influent Nitrate Concentration of 0.38 mg/L N, 2nd Run, 3/27/08

2nd run **3/27/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	1.377	saturated port 1	0	0.976	saturated port 1	0	0.525
saturated port 2	4.333333	8.951	saturated port 2	3.9	0.625	saturated port 2	4.116667	0.274
saturated port 3	9.383333	9.201	saturated port 3	8.45	1.277	saturated port 3	8.7746	0.725
bottom of saturated	13.85	0.825	bottom of saturated	12.46667	1.227	bottom of saturated	13.16667	0.625

Table 13B: TN for Influent Nitrate Concentration of 0.38 mg/L N, 3rd Run, 3/28/08

3rd run **3/28/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	1.377	saturated port 1	0	0.825	saturated port 1	0	0.525
saturated port 2	4.333333	8.7	saturated port 2	3.9	0.876	saturated port 2	4.116667	0.123
saturated port 3	9.383333	9.051	saturated port 3	8.45	1.126	saturated port 3	8.7746	0.374
bottom of saturated	13.85	1.076	bottom of saturated	12.46667	1.026	bottom of saturated	13.16667	0.625

Table 14B: TN for Influent Nitrate Concentration of 1.26 mg/L N, 1st Run, 3/31/08

1st run **3/31/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	2.43	saturated port 1	0	2.481	saturated port 1	0	1.126
saturated port 2	4.333333	0.825	saturated port 2	3.9	2.129	saturated port 2	4.116667	0.073
saturated port 3	9.383333	3.032	saturated port 3	8.45	0.725	saturated port 3	8.7746	0.474
bottom of saturated	13.85	1.327	bottom of saturated	12.46667	0.976	bottom of saturated	13.16667	0.625

Table 15B: TN for Influent Nitrate Concentration of 1.26 mg/L N, 2nd Run, 4/1/08

2nd run **4/1/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	2.079	saturated port 1	0	4.236	saturated port 1	0	0.474
saturated port 2	4.333333	2.481	saturated port 2	3.9	0.525	saturated port 2	4.116667	0.173
saturated port 3	9.383333	3.434	saturated port 3	8.45	1.678	saturated port 3	8.7746	0.424
bottom of saturated	13.85	1.728	bottom of saturated	12.46667	1.277	bottom of saturated	13.16667	0.625

Table 16B: TN for Influent Nitrate Concentration of 1.26 mg/L N, 3rd Run, 4/2/08

3rd run **4/2/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	2.029	saturated port 1	0	3.985	saturated port 1	0	0.374
saturated port 2	4.333333	2.33	saturated port 2	3.9	0.525	saturated port 2	4.116667	0.274
saturated port 3	9.383333	3.333	saturated port 3	8.45	1.578	saturated port 3	8.7746	0.374
bottom of saturated	13.85	1.728	bottom of saturated	12.46667	1.227	bottom of saturated	13.16667	0.575

Table 17B: TN for Influent Nitrate Concentration of 2.53 mg/L N, 1st Run, 4/7/08

1st run **4/7/2008**

Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	2.33	saturated port 1	0	1.929	saturated port 1	0	1.829
saturated port 2	4.333333	2.23	saturated port 2	3.9	0.725	saturated port 2	4.116667	0.274
saturated port 3	9.383333	3.133	saturated port 3	8.45	0.424	saturated port 3	8.7746	0.625
bottom of saturated	13.85	1.979	bottom of saturated	12.46667	0.876	bottom of saturated	13.16667	0.224

Table 18B: TN for Influent Nitrate Concentration of 2.53 mg/L N, 2nd Run, 4/8/08

2nd run	**4/8/2008**							
Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	3.183	saturated port 1	0	3.283	saturated port 1	0	2.029
saturated port 2	4.333333	2.982	saturated port 2	3.9	0.474	saturated port 2	4.116667	0.173
saturated port 3	9.383333	1.778	saturated port 3	8.45	0.725	saturated port 3	8.7746	0.123
bottom of saturated	13.85	1.427	bottom of saturated	12.46667	0.474	bottom of saturated	13.16667	0.324

Table 19B: TN for Influent Nitrate Concentration of 2.53 mg/L N, 3rd Run, 4/9/08

3rd run	**4/9/2008**							
Control Column			Media 1			Media 2		
TN			TN			TN		
Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)	Location	Detention time (hrs)	Conc. (mg/L as N)
saturated port 1	0	3.233	saturated port 1	0	3.333	saturated port 1	0	1.979
saturated port 2	4.333333	2.982	saturated port 2	3.9	0.374	saturated port 2	4.116667	0.023
saturated port 3	9.383333	1.879	saturated port 3	8.45	0.775	saturated port 3	8.7746	0.023
bottom of saturated	13.85	1.477	bottom of saturated	12.46667	0.424	bottom of saturated	13.16667	0.224

Table 20B: Ammonia for Influent Nitrate Concentration of 0.38 mg/L N, 1st Run, 3/26/08

1st run	**3/26/2008**							
Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	1E-04	saturated port 1	0	0.003	saturated port 1	0	0.005
saturated port 3	9.383333	0.043	saturated port 3	8.45	0.074	saturated port 3	8.7746	0.093
bottom of saturated	13.85	0.139	bottom of saturated	12.46667	0.022	bottom of saturated	13.16667	0.119

Table 21B: Ammonia for Influent Nitrate Concentration of 0.38 mg/L N, 2nd Run, 3/27/08

2nd run	**3/27/2008**							
Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.001	saturated port 1	0	0.007	saturated port 1	0	0.003
saturated port 2	4.333333	0.025	saturated port 2	3.9	0.017	saturated port 2	4.116667	0.054
saturated port 3	9.383333	0.016	saturated port 3	8.45	0.029	saturated port 3	8.7746	0.075
bottom of saturated	13.85	0.184	bottom of saturated	12.46667	0.028	bottom of saturated	13.16667	0.124

Table 22B: Ammonia for Influent Nitrate Concentration of 0.38 mg/L N, 3rd Run, 3/28/08

3rd run **3/28/2008**

Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.01	saturated port 1	0	0.005	saturated port 1	0	9E-04
saturated port 2	4.333333	0.029	saturated port 2	3.9	0.027	saturated port 2	4.116667	0.057
saturated port 3	9.383333	0.014	saturated port 3	8.45	0.047	saturated port 3	8.7746	0.091
bottom of saturated	13.85	0.219	bottom of saturated	12.46667	0.038	bottom of saturated	13.16667	0.135

Table 23B: Ammonia for Influent Nitrate Concentration of 1.26 mg/L N, 1st Run, 3/31/08

1st run **3/31/2008**

Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.016	saturated port 1	0	0.03	saturated port 1	0	0.004
saturated port 2	4.333333	0.014	saturated port 2	3.9	0.02	saturated port 2	4.116667	0.016
saturated port 3	9.383333	0.131	saturated port 3	8.45	0.058	saturated port 3	8.7746	0.031
bottom of saturated	13.85	0.249	bottom of saturated	12.46667	0.042	bottom of saturated	13.16667	0.075

Table 24B: Ammonia for Influent Nitrate Concentration of 1.26 mg/L N, 2nd Run, 4/1/08

2nd run **4/1/2008**

Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.004	saturated port 1	0	0.016	saturated port 1	0	0.01
saturated port 2	4.333333	0.01	saturated port 2	3.9	0.062	saturated port 2	4.116667	0.079
saturated port 3	9.383333	0.088	saturated port 3	8.45	0.134	saturated port 3	8.7746	0.079
bottom of saturated	13.85	0.273	bottom of saturated	12.46667	0.1	bottom of saturated	13.16667	0.092

Table 25B: Ammonia for Influent Nitrate Concentration of 1.26 mg/L N, 3rd Run, 4/2/08

3rd run **4/2/2008**

Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.018	saturated port 1	0	0.034	saturated port 1	0	0.018
saturated port 2	4.333333	0.023	saturated port 2	3.9	0.066	saturated port 2	4.116667	0.019
saturated port 3	9.383333	0.116	saturated port 3	8.45	0.108	saturated port 3	8.7746	0.056
bottom of saturated	13.85	0.287	bottom of saturated	12.46667	0.113	bottom of saturated	13.16667	0.107

Table 26B: Ammonia for Influent Nitrate Concentration of 2.53 mg/L N, 1st Run, 4/7/08

1st run	**4/7/2008**							
Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.03	saturated port 1	0	0.054	saturated port 1	0	0.006
saturated port 2	4.333333	-0	saturated port 2	3.9	0.051	saturated port 2	4.116667	0.052
saturated port 3	9.383333	0.189	saturated port 3	8.45	0.102	saturated port 3	8.7746	0.034
bottom of saturated	13.85	0.397	bottom of saturated	12.46667	0.106	bottom of saturated	13.16667	0.088

Table 27B: Ammonia for Influent Nitrate Concentration of 2.53 mg/L N, 2nd Run, 4/8/08

2nd run	**4/8/2008**							
Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.012	saturated port 1	0	0.025	saturated port 1	0	-7E-04
saturated port 2	4.333333	0.008	saturated port 2	3.9	0.061	saturated port 2	4.116667	0.008
saturated port 3	9.383333	0.149	saturated port 3	8.45	0.117	saturated port 3	8.7746	0.024
bottom of saturated	13.85	0.399	bottom of saturated	12.46667	0.121	bottom of saturated	13.16667	0.065

Table 28B: Ammonia for Influent Nitrate Concentration of 2.53 mg/L N, 3rd Run, 4/9/08

3rd run **4/9/2008**

Control Column			Media 1			Media 2		
Ammonia			Ammonia			Ammonia		
Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)	Location	Detention time (hrs)	Conc. (mg/L NH_3 as N)
saturated port 1	0	0.033	saturated port 1	0	0.052	saturated port 1	0	0.01
saturated port 2	4.333333	0.003	saturated port 2	3.9	0.054	saturated port 2	4.116667	0.038
saturated port 3	9.383333	0.142	saturated port 3	8.45	0.106	saturated port 3	8.7746	0.02
bottom of saturated	13.85	0.401	bottom of saturated	12.46667	0.111	bottom of saturated	13.16667	0.06

Table 29B: Nitrite for Influent Nitrate Concentration of 0.38 mg/L N, 1st Run, 3/26/08

1st run **3/26/2008**

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.02	saturated port 1	0	0.02	saturated port 1	0	0.019
saturated port 3	9.383333	0.017	saturated port 3	8.45	0.016	saturated port 3	8.7746	0.02
bottom of saturated	13.85	0.041	bottom of saturated	12.46667	0.017	bottom of saturated	13.16667	0.019

Table 30B: Nitrite for Influent Nitrate Concentration of 0.38 mg/L N, 2nd Run, 3/27/08

2nd run **3/27/2008**

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.023	saturated port 1	0	0.02	saturated port 1	0	0.019
saturated port 2	4.333333	0.018	saturated port 2	3.9	0.016	saturated port 2	4.116667	0.018
saturated port 3	9.383333	0.018	saturated port 3	8.45	0.017	saturated port 3	8.7746	0.018
bottom of saturated	13.85	0.024	bottom of saturated	12.46667	0.017	bottom of saturated	13.16667	0.02

Table 31B: Nitrite for Influent Nitrate Concentration of 0.38 mg/L N, 3rd Run, 3/28/08

3rd run **3/28/2008**

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.031	saturated port 1	0	0.021	saturated port 1	0	0.018
saturated port 2	4.333333	0.03	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.016
saturated port 3	9.383333	0.029	saturated port 3	8.45	0.016	saturated port 3	8.7746	0.018
bottom of saturated	13.85	0.024	bottom of saturated	12.46667	0.017	bottom of saturated	13.16667	0.018

Table 32B: Nitrite for Influent Nitrate Concentration of 1.26 mg/L N, 1st Run, 3/31/08

1st run **3/31/2008**

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.064	saturated port 1	0	0.055	saturated port 1	0	0.019
saturated port 2	4.333333	0.017	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.018
saturated port 3	9.383333	0.027	saturated port 3	8.45	0.02	saturated port 3	8.7746	0.019
bottom of saturated	13.85	0.028	bottom of saturated	12.46667	0.018	bottom of saturated	13.16667	0.021

Table 33B: Nitrite for Influent Nitrate Concentration of 1.26 mg/L N, 2nd Run, 4/1/08

2nd run **4/1/2008**

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.076	saturated port 1	0	0.032	saturated port 1	0	0.019
saturated port 2	4.333333	0.018	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.017
saturated port 3	9.383333	0.029	saturated port 3	8.45	0.017	saturated port 3	8.7746	0.017
bottom of saturated	13.85	0.019	bottom of saturated	12.46667	0.016	bottom of saturated	13.16667	0.018

Table 34B: Nitrite for Influent Nitrate Concentration of 1.26 mg/L N, 3rd Run, 4/2/08

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.041	saturated port 1	0	0.024	saturated port 1	0	0.021
saturated port 2	4.333333	0.019	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.02
saturated port 3	9.383333	0.034	saturated port 3	8.45	0.016	saturated port 3	8.7746	0.018
bottom of saturated	13.85	0.02	bottom of saturated	12.46667	0.017	bottom of saturated	13.16667	0.018

Table 35B: Nitrite for Influent Nitrate Concentration of 2.53 mg/L N, 1st Run, 4/7/08

1st run **4/7/2008**

Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.069	saturated port 1	0	0.026	saturated port 1	0	0.019
saturated port 2	4.333333	0.019	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.019
saturated port 3	9.383333	0.026	saturated port 3	8.45	0.018	saturated port 3	8.7746	0.021
bottom of saturated	13.85	0.022	bottom of saturated	12.46667	0.018	bottom of saturated	13.16667	0.018

Table 36B: Nitrite for Influent Nitrate Concentration of 2.53 mg/L N, 2nd Run, 4/8/08

2nd run	**4/8/2008**							
Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.064	saturated port 1	0	0.05	saturated port 1	0	0.022
saturated port 2	4.333333	0.02	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.019
saturated port 3	9.383333	0.025	saturated port 3	8.45	0.017	saturated port 3	8.7746	0.019
bottom of saturated	13.85	0.018	bottom of saturated	12.46667	0.016	bottom of saturated	13.16667	0.018

Table 37B: Nitrite for Influent Nitrate Concentration of 2.53 mg/L N, 3rd Run, 4/9/08

3rd run	**4/9/2008**							
Control Column			Media 1			Media 2		
Nitrite			Nitrite			Nitrite		
Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)	Location	Detention time (hrs)	Conc. (mg/L NO_2^- as N)
saturated port 1	0	0.062	saturated port 1	0	0.036	saturated port 1	0	0.02
saturated port 2	4.333333	0.02	saturated port 2	3.9	0.018	saturated port 2	4.116667	0.019
saturated port 3	9.383333	0.026	saturated port 3	8.45	0.017	saturated port 3	8.7746	0.02
bottom of saturated	13.85	0.02	bottom of saturated	12.46667	0.017	bottom of saturated	13.16667	0.018

Table 38B: Ortho-P for Influent Ortho-P Concentration of 0.125 mg/L PO_4-P, 1st Run, 4/22/08

1st run 4/22/2008

Control column			Media 1			Media 2		
Ortho P			Ortho P			Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.069	saturated port 1	0	0.131	saturated port 1	0	0.194
saturated port 2	4.333333	0.146	saturated port 2	3.9	0.109	saturated port 2	4.116667	0.122
saturated port 3	9.383333	0.186	saturated port 3	8.45	0.1	saturated port 3	8.7746	0.103
bottom of saturated	13.85	0.294	bottom of saturated	12.46667	0.071	bottom of saturated	13.16667	0.099

Table 39B: Ortho-P for Influent Ortho-P Concentration of 0.125 mg/L PO_4-P, 2nd Run, 4/23/08

2nd run 4/23/2008

Control column			Media 1			Media 2		
Ortho P			Ortho P			Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.109	saturated port 1	0	0.137	saturated port 1	0	0.137
saturated port 2	4.333333	0.146	saturated port 2	3.9	0.147	saturated port 2	4.116667	0.091
saturated port 3	9.383333	0.168	saturated port 3	8.45	0.083	saturated port 3	8.7746	0.082
bottom of saturated	13.85	0.28	bottom of saturated	12.46667	0.044	bottom of saturated	13.16667	0.075

Table 40B: Ortho-P for Influent Ortho-P Concentration of 0.125 mg/L PO_4-P, 3rd Run, 4/24/08

3rd run 4/24/2008

Control column Ortho P			Media 1 Ortho P			Media 2 Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.092	saturated port 1	0	0.127	saturated port 1	0	0.116
saturated port 2	4.333333	0.134	saturated port 2	3.9	0.075	saturated port 2	4.116667	0.083
saturated port 3	9.383333	0.139	saturated port 3	8.45	0.095	saturated port 3	8.7746	0.094
bottom of saturated	13.85	0.336	bottom of saturated	12.46667	0.067	bottom of saturated	13.16667	0.078

Table 41B: Ortho-P for Influent Ortho-P Concentration of 0.361 mg/L PO_4-P, 1st Run, 4/28/08

1st run 4/28/2008

Control Column Ortho P			Media 1 Ortho P			Media 2 Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.129	saturated port 1	0	0.144	saturated port 1	0	0.094
saturated port 2	4.333333	0.147	saturated port 2	3.9	0.087	saturated port 2	4.116667	0.103
saturated port 3	9.383333	0.15	saturated port 3	8.45	0.083	saturated port 3	8.7746	0.096
bottom of saturated	13.85	0.293	bottom of saturated	12.46667	0.043	bottom of saturated	13.16667	0.054

Table 42B: Ortho-P for Influent Ortho-P Concentration of 0.361 mg/L PO_4-P, 2nd Run, 4/29/08

2nd run 4/29/2008

Control Column — Ortho P; Media 1 — Ortho P; Media 2 — Ortho P

Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.1	saturated port 1	0	0.157	saturated port 1	0	0.13
saturated port 2	4.333333	0.142	saturated port 2	3.9	0.118	saturated port 2	4.116667	0.104
saturated port 3	9.383333	0.155	saturated port 3	8.45	0.111	saturated port 3	8.7746	0.09
bottom of saturated	13.85	0.285	bottom of saturated	12.46667	0.077	bottom of saturated	13.16667	0.07

Table 43B: Ortho-P for Influent Ortho-P Concentration of 0.361 mg/L PO_4-P, 3rd Run, 4/30/08

3rd run 4/30/2008

Control Column — Ortho P; Media 1 — Ortho P; Media 2 — Ortho P

Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.112	saturated port 1	0	0.147	saturated port 1	0	0.131
saturated port 2	4.333333	0.146	saturated port 2	3.9	0.054	saturated port 2	4.116667	0.074
saturated port 3	9.383333	0.143	saturated port 3	8.45	0.082	saturated port 3	8.7746	0.073
bottom of saturated	13.85	0.302	bottom of saturated	12.46667	0.031	bottom of saturated	13.16667	0.049

Table 44B: Ortho-P for Influent Ortho-P Concentration of 0.785 mg/L PO_4-P, 1st Run, 5/7/08

1st run 5/7/2008

Control Column			Media 1			Media 2		
Ortho P			Ortho P			Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.31	saturated port 1	0	0.195	saturated port 1	0	0.284
saturated port 2	4.333333	0.202	saturated port 2	3.9	0.279	saturated port 2	4.116667	0.206
saturated port 3	9.383333	0.173	saturated port 3	8.45	0.053	saturated port 3	8.7746	0.161
bottom of saturated	13.85	0.339	bottom of saturated	12.46667	0.099	bottom of saturated	13.16667	0.12

Table 45B: Ortho-P for Influent Ortho-P Concentration of 0.785 mg/L PO_4-P, 2nd Run, 5/8/08

2nd run 5/8/2008

Control Column			Media 1			Media 2		
Ortho P			Ortho P			Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.086	saturated port 1	0	0.155	saturated port 1	0	0.13
saturated port 2	4.333333	0.143	saturated port 2	3.9	0.168	saturated port 2	4.116667	0.094
saturated port 3	9.383333	0.172	saturated port 3	8.45	0.035	saturated port 3	8.7746	0.083
bottom of saturated	13.85	0.358	bottom of saturated	12.46667	0.048	bottom of saturated	13.16667	0.096

Table 46B: Ortho-P for Influent Ortho-P Concentration of 0.785 mg/L PO_4-P, 3rd Run, 5/9/08

3rd run **5/9/2008**

Control Column			Media 1			Media 2		
Ortho P			Ortho P			Ortho P		
Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)	Location	Detention time (hrs)	Conc. (mg/L PO4- as P)
saturated port 1	0	0.199	saturated port 1	0	0.161	saturated port 1	0	0.214
saturated port 2	4.333333	0.167	saturated port 2	3.9	0.173	saturated port 2	4.116667	0.161
saturated port 3	9.383333	0.173	saturated port 3	8.45	0.049	saturated port 3	8.7746	0.127
bottom of saturated	13.85	0.357	bottom of saturated	12.46667	0.057	bottom of saturated	13.16667	0.103

Table 47B: Total Phosphorus for Influent Ortho-P Concentration of 0.125 mg/L PO_4-P, 1st Run, 4/22/08

1st run **4/22/2008**

Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.078	saturated port 1	0	0.451	saturated port 1	0	0.752
saturated port 2	4.33	0.069	saturated port 2	3.9	0.054	saturated port 2	4.116667	0.066
saturated port 3	9.383333	0.067	saturated port 3	8.45	0.063	saturated port 3	8.7746	0.054
bottom of saturated	13.85	0.156	bottom of saturated	12.4667	0.067	bottom of saturated	13.16667	0.048

Table 48B: Total Phosphorus for Influent Ortho-P Concentration of 0.125 mg/L PO_4-P, 2nd Run, 4/23/08

2nd run	**4/23/2008**							
Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.058	saturated port 1	0	0.416	saturated port 1	0	0.266
saturated port 2	4.33	0.066	saturated port 2	3.9	0.06	saturated port 2	4.116667	0.054
saturated port 3	9.383333	0.091	saturated port 3	8.45	0.081	saturated port 3	8.7746	0.068
bottom of saturated	13.85	0.233	bottom of saturated	12.4667	0.098	bottom of saturated	13.16667	0.075

Table 49B: Total Phosphorus for Influent Ortho-P Concentration of 0.125 mg/L PO_4-P, 3rd Run, 4/24/08

3rd run	**4/24/2008**							
Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.11	saturated port 1	0	0.605	saturated port 1	0	1.305
saturated port 2	4.33	0.108	saturated port 2	3.9	0.094	saturated port 2	4.116667	0.092
saturated port 3	9.383333	0.113	saturated port 3	8.45	0.103	saturated port 3	8.7746	0.076
bottom of saturated	13.85	0.274	bottom of saturated	12.4667	0.114	bottom of saturated	13.16667	0.085

Table 50B: Total Phosphorus for Influent Ortho-P Concentration of 0.361 mg/L PO_4-P, 1st Run, 4/28/08

1st run **4/28/2008**

Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	1.035	saturated port 1	0	0.927	saturated port 1	0	0.704
saturated port 2	4.33	0.148	saturated port 2	3.9	0.108	saturated port 2	4.116667	0.085
saturated port 3	9.383333	0.092	saturated port 3	8.45	0.074	saturated port 3	8.7746	0.157
bottom of saturated	13.85	0.224	bottom of saturated	12.46667	0.154	bottom of saturated	13.16667	0.263

Table 51B: Total Phosphorus for Influent Ortho-P Concentration of 0.361 mg/L PO_4-P, 2nd Run, 4/29/08

2nd run **4/29/2008**

Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.073	saturated port 1	0	0.959	saturated port 1	0	0.31
saturated port 2	4.33	0.071	saturated port 2	3.9	0.061	saturated port 2	4.116667	0.056
saturated port 3	9.383333	0.086	saturated port 3	8.45	0.086	saturated port 3	8.7746	0.083
bottom of saturated	13.85	0.238	bottom of saturated	12.46667	0.105	bottom of saturated	13.16667	0.08

Table 52B: Total Phosphorus for Influent Ortho-P Concentration of 0.361 mg/L PO_4-P, 3rd Run, 4/30/08

3rd run **4/30/2008**

Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.091	saturated port 1	0	0.877	saturated port 1	0	0.367
saturated port 2	4.33	0.102	saturated port 2	3.9	0.078	saturated port 2	4.116667	0.077
saturated port 3	9.383333	0.12	saturated port 3	8.45	0.096	saturated port 3	8.7746	0.089
bottom of saturated	13.85	0.243	bottom of saturated	12.46667	0.114	bottom of saturated	13.16667	0.097

Table 53B: Total Phosphorus for Influent Ortho-P Concentration of 0.785 mg/L PO_4-P, 1st Run, 5/7/08

1st run **5/7/2008**

Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	1.265	saturated port 1	0	1.496	saturated port 1	0	0.334
saturated port 2	4.33	0.112	saturated port 2	3.9	0.092	saturated port 2	4.116667	0.101
saturated port 3	9.383333	0.142	saturated port 3	8.45	0.137	saturated port 3	8.7746	0.092
bottom of saturated	13.85	0.261	bottom of saturated	12.46667	0.125	bottom of saturated	13.16667	0.083

Table 54B: Total Phosphorus for Influent Ortho-P Concentration of 0.785 mg/L PO_4-P, 2nd Run, 5/8/08

2nd run	**5/8/2008**							
Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.082	saturated port 1	0	0.779	saturated port 1	0	0.222
saturated port 2	4.33	0.115	saturated port 2	3.9	0.129	saturated port 2	4.116667	0.102
saturated port 3	9.383333	0.15	saturated port 3	8.45	0.121	saturated port 3	8.7746	0.097
bottom of saturated	13.85	0.293	bottom of saturated	12.46667	0.146	bottom of saturated	13.16667	0.096

Table 55B: Total Phosphorus for Influent Ortho-P Concentration of 0.785 mg/L PO_4-P, 3rd Run, 5/9/08

3rd run	**5/9/2008**							
Control Column			Media 1			Media 2		
TP			TP			TP		
Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)	Location	Detention time (hrs)	Conc. (mg/L as P)
saturated port 1	0	0.082	saturated port 1	0	0.779	saturated port 1	0	0.222
saturated port 2	4.33	0.115	saturated port 2	3.9	0.129	saturated port 2	4.116667	0.102
saturated port 3	9.383333	0.15	saturated port 3	8.45	0.121	saturated port 3	8.7746	0.097
bottom of saturated	13.85	0.293	bottom of saturated	12.46667	0.146	bottom of saturated	13.16667	0.096

Table 56B: Orthophosphate and Total Phosphorus in Reservoir

Date	Reservoir Orthophosphate Concentration mg/L PO_4-P	Reservoir TP Concentration mg/L as P
4/22/2008	0.125	0.140
4/23/2008	0.125	0.140
4/24/2008	0.125	0.140
4/28/2008	0.361	0.343
4/29/2008	0.361	0.343
4/30/2008	0.361	0.343
5/7/2008	0.785	0.551
5/8/2008	0.785	0.551
5/9/2008	0.785	0.551

Table 57B: pH for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 1st Run, 3/26/08

1st run **3/26/2008**

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.4	reservoir		7.4	reservoir		7.4
saturated port 1	0	7.23	saturated port 1	0	7.19	saturated port 1	0	7.17
saturated port 2	4.33	7.03	saturated port 2	3.9	7.27	saturated port 2	4.116667	7.5
saturated port 3	9.383333	6.92	saturated port 3	8.45	7.06	saturated port 3	8.7746	7.59
bottom of saturated	13.85	6.97	bottom of saturated	12.46667	6.9	bottom of saturated	13.16667	7.63

Table 58B: pH for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 2nd Run, 3/27/08

2nd run	**3/27/2008**							
Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.42	reservoir		7.42	reservoir		7.42
saturated port 1	0	7.3	saturated port 1	0	7.2	saturated port 1	0	7.25
saturated port 2	4.33	7.1	saturated port 2	3.9	7.04	saturated port 2	4.116667	7.6
saturated port 3	9.383333	7.01	saturated port 3	8.45	7.06	saturated port 3	8.7746	7.66
bottom of saturated	13.85	6.9	bottom of saturated	12.46667	7.09	bottom of saturated	13.16667	7.65

Table 59B: pH for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 3rd Run, 3/28/08

3rd run	**3/28/2008**							
Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.39	reservoir		7.39	reservoir		7.39
saturated port 1	0	7.25	saturated port 1	0	7.2	saturated port 1	0	7.19
saturated port 2	4.33	7.08	saturated port 2	3.9	7.2	saturated port 2	4.116667	7.56
saturated port 3	9.383333	6.97	saturated port 3	8.45	7.08	saturated port 3	8.7746	7.61
bottom of saturated	13.85	6.94	bottom of saturated	12.46667	7.01	bottom of saturated	13.16667	7.62

Table 60B: pH for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, Average of Runs 1-3, 3/26/08- 3/28/08

Average

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	Avg. pH	Location	Detention time (hrs)	Avg. pH	Location	Detention time (hrs)	Avg. pH
reservoir		7.4	reservoir		7.4	reservoir		7.4
saturated port 1	0	7.26	saturated port 1	0	7.2	saturated port 1	0	7.2
saturated port 2	4.33	7.07	saturated port 2	3.9	7.17	saturated port 2	4.11667	7.55
saturated port 3	9.38333	6.97	saturated port 3	8.45	7.07	saturated port 3	8.7746	7.62
bottom of saturated	13.85	6.94	bottom of saturated	12.4667	7	bottom of saturated	13.1667	7.63

Table 61B: pH for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 1st Run, 3/31/08

1st run **3/31/2008**

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.1	reservoir		7.1	reservoir		7.1
saturated port 1	0	7.01	saturated port 1	0	6.8	saturated port 1	0	6.76
saturated port 2	4.33	6.89	saturated port 2	3.9	6.9	saturated port 2	4.11667	7.59
saturated port 3	9.383333	6.82	saturated port 3	8.45	6.98	saturated port 3	8.7746	7.62
bottom of saturated	13.85	6.74	bottom of saturated	12.4667	7.03	bottom of saturated	13.1667	7.6

Table 61B: pH for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 2nd Run, 4/1/08

2nd run	**4/1/2008**							
Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.15	reservoir		7.15	reservoir		7.15
saturated port 1	0	6.87	saturated port 1	0	6.8	saturated port 1	0	6.96
saturated port 2	4.33	6.86	saturated port 2	3.9	6.85	saturated port 2	4.11667	7.62
saturated port 3	9.383333	6.83	saturated port 3	8.45	6.85	saturated port 3	8.7746	7.66
bottom of saturated	13.85	6.79	bottom of saturated	12.4667	6.74	bottom of saturated	13.1667	7.63

Table 62B: pH for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 3rd Run, 4/2/08

3rd run	**4/2/2008**							
Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.13	reservoir		7.13	reservoir		7.13
saturated port 1	0	6.94	saturated port 1	0	6.84	saturated port 1	0	6.85
saturated port 2	4.33	6.87	saturated port 2	3.9	6.83	saturated port 2	4.11667	7.6
saturated port 3	9.383333	6.84	saturated port 3	8.45	6.9	saturated port 3	8.7746	7.62
bottom of saturated	13.85	6.76	bottom of saturated	12.4667	6.85	bottom of saturated	13.1667	7.64

Table 63B: pH for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, Average of Runs 1-3, 3/31/08 - 4/2/08

Average

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	Avg. pH	Location	Detention time (hrs)	Avg. pH	Location	Detention time (hrs)	Avg. pH
reservoir		7.13	reservoir		7.13	reservoir		7.13
saturated port 1	0	6.94	saturated port 1	0	6.81	saturated port 1	0	6.86
saturated port 2	4.33	6.87	saturated port 2	3.9	6.86	saturated port 2	4.11667	7.6
saturated port 3	9.383333	6.83	saturated port 3	8.45	6.91	saturated port 3	8.7746	7.63
bottom of saturated	13.85	6.76	bottom of saturated	12.4667	6.87	bottom of saturated	13.1667	7.62

Table 64B: pH for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 1st Run, 4/7/08

1st run **4/7/2008**

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.1	reservoir		7.1	reservoir		7.1
saturated port 1	0	6.89	saturated port 1	0	6.84	saturated port 1	0	6.83
saturated port 2	4.33	6.8	saturated port 2	3.9	6.78	saturated port 2	4.11667	7.58
saturated port 3	9.383333	6.8	saturated port 3	8.45	6.82	saturated port 3	8.7746	7.6
bottom of saturated	13.85	6.79	bottom of saturated	12.4667	6.8	bottom of saturated	13.1667	7.62

Table 65B: pH for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 2nd Run, 4/8/08

2nd run **4/8/2008**

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.13	reservoir		7.13	reservoir		7.13
saturated port 1	0	6.85	saturated port 1	0	6.86	saturated port 1	0	6.84
saturated port 2	4.33	6.83	saturated port 2	3.9	6.8	saturated port 2	4.11667	7.6
saturated port 3	9.383333	6.78	saturated port 3	8.45	6.75	saturated port 3	8.7746	7.63
bottom of saturated	13.85	6.73	bottom of saturated	12.4667	6.82	bottom of saturated	13.1667	7.61

Table 66B: pH for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 3rd Run, 4/9/08

3rd run **4/9/2008**

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH	Location	Detention time (hrs)	pH
reservoir		7.09	reservoir		7.09	reservoir		7.09
saturated port 1	0	6.82	saturated port 1	0	6.82	saturated port 1	0	6.8
saturated port 2	4.33	6.76	saturated port 2	3.9	6.85	saturated port 2	4.11667	7.61
saturated port 3	9.383333	6.81	saturated port 3	8.45	6.8	saturated port 3	8.7746	7.59
bottom of saturated	13.85	6.73	bottom of saturated	12.4667	6.75	bottom of saturated	13.1667	7.65

Table 67B: pH for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, Average of Runs 1-3, 4/7/08-4/9/08

Average

Control Column			Media 1			Media 2		
pH			pH			pH		
Location	Detention time (hrs)	Avg. pH	Location	Detention time (hrs)	Avg. pH	Location	Detention time (hrs)	Avg. pH
reservoir		7.11	reservoir		7.11	reservoir		7.11
saturated port 1	0	6.85	saturated port 1	0	6.84	saturated port 1	0	6.82
saturated port 2	4.33	6.8	saturated port 2	3.9	6.81	saturated port 2	4.11667	7.6
saturated port 3	9.383333	6.8	saturated port 3	8.45	6.79	saturated port 3	8.7746	7.61
bottom of saturated	13.85	6.75	bottom of saturated	12.4667	6.79	bottom of saturated	13.1667	7.63

Table 68B: DO for Influent Nitrate Concentration of 0.38 mg/L NO_3-N, 3rd Run, 3/28/08

Control		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.56
saturated port 1	0.00	0.78
saturated port 2	4.33	0.44
saturated port 3	9.38	0.22
bottom of saturated	13.85	0.14
Media 1		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.56
saturated port 1	0.00	0.67
saturated port 2	3.90	0.27
saturated port 3	8.45	0.18
bottom of saturated	12.47	0.10
Media 2		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.56
saturated port 1	0.00	0.66
saturated port 2	4.12	0.18
saturated port 3	8.77	0.39
bottom of saturated	13.17	0.19

Table 69B: DO for Influent Nitrate Concentration of 1.26 mg/L NO_3-N, 3rd Run, 4/2/08

Control		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.46
saturated port 1	0.00	0.61
saturated port 2	4.33	0.50
saturated port 3	9.38	0.15
bottom of saturated	13.85	0.21
Media 1		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.46
saturated port 1	0.00	0.71
saturated port 2	3.90	0.32
saturated port 3	8.45	0.23
bottom of saturated	12.47	0.11
Media 2		
Location	Detention time (hrs)	DO mg/L
reservoir	-	2.46
saturated port 1	0.00	0.68
saturated port 2	4.12	0.19
saturated port 3	8.77	0.45
bottom of saturated	13.17	0.24

Table 70B: DO for Influent Nitrate Concentration of 2.53 mg/L NO_3-N, 3rd Run, 4/9/08

Control		
Location	Detention time (hrs)	DO mg/L
reservoir	-	3.01
saturated port 1	0.00	0.70
saturated port 2	4.33	0.63
saturated port 3	9.38	0.25
bottom of saturated	13.85	0.09
Media 1		
Location	Detention time (hrs)	DO mg/L
reservoir	-	3.01
saturated port 1	0.00	0.76
saturated port 2	3.90	0.36
saturated port 3	8.45	0.20
bottom of saturated	12.47	0.15
Media 2		
Location	Detention time (hrs)	DO mg/L
reservoir	-	3.01
saturated port 1	0.00	0.81
saturated port 2	4.12	0.34
saturated port 3	8.77	0.41
bottom of saturated	13.17	0.31

APPENDIX C: PROCEDURES

Nitrogen, Total
Method 10071

1. Turn on the DRB200 Reactor and heat to 105°C.
2. Using a funnel, add the contents of one Total Nitrogen Persulfate Reagent Powder Pillow to each of two Total Nitrogen Hydroxide Digestion Reagent vials. Wipe off any reagent that may get on the lid or the tube threads.
3. **Prepared Sample**: Add 2mL of sample to one vial.
   Blank Preparation: Add 2 mL of the deionized water included in the kit to a second vial. **Note:** Use only water that is free of all Nitrogen-containing species as a substitute for the provided deionized water.
4. Cap both vials. Shake vigorously for at least 30 seconds to mix. The persulfate reagent may not dissolve completely after shaking. This will not affect accuracy.
5. Insert the vials in the reactor. Heat for exactly 30 minutes.
6. Using finger cots, immediately remove the hot vials from the reactor. Cool the vials to room temperature.
7. Select the test. Install the Light Shield in Cell Compartment #2.
8. Remove the caps from the digested vials and add the contents of one Total Nitrogen (TN) Reagent A Powder Pillow to each vial.
9. Cap the tubes and shake for 15 seconds.
10. Press **TIMER>OK**. A three-minute reaction period will begin.
11. After the timer expires, remove the caps from the vials and add one TN Reagent B Powder Pillow to each vial.
12. Cap the tubes and shake for 15 seconds. The reagent will not completely dissolve. This will not affect accuracy. The solution will begin to turn yellow.
13. Press **TIMER>OK**. A two-minute reaction period will begin.
14. After the timer expires, remove the caps from two TN Reagent C vials and add 2 mL of digested, treated sample to one vial. Add 2 mL of digested, treated reagent blank to the second TN Reagent C vial.
15. Cap the vials and invert ten times to mix. Use slow, deliberate inversions for complete recovery. The tubes will be warm to the touch.
16. Press **TIMER>OK**. A five-minute reaction period will begin. The yellow color will intensify.
17. Wipe the reagent blank and insert it into the 16-mm round cell holder.
18. Press **ZERO**. The display will show: 0.0mg/L N
19. Wipe the reagent vial and insert it into the 16-mm round cell holder.
20. Press **READ**. Results are in mg/L N.

Phosphorus, Reactive Orthophosphate

Method 8048

1. Press **STORED PROGRAMS**
2. Select the test: 490 P React. PV
3. Fill a square sample cell with 10-mL of sample.
4. **Prepared Sample:** Add the contents of one PhosVer 3 Phosphate Powder Pillow to the cell. Immediately stopper and shake vigorously for 30 seconds.
5. Press **TIMER>OK.** A two-minute reaction period will begin. If the sample was digested using the Acid Persulfate digestion, a ten-minute reaction period is required.
6. **Blank Preparation:** Fill a second square sample cell with 10 mL of sample.
7. When the timer expires, wipe the blank and insert it into the cell holder with the fill line facing right. Press **ZERO**. The display will show: 0.00 mg/L PO_4^{3-}
8. Wipe the prepared sample and insert it into the cell holder with the fill line facing right. Press **READ**. Results are in mg/L PO_4^{3-}.

Nitrogen, Nitrate
Method 8192

1. Press **STORED PROGRAMS**
2. Select the test: 351 N Nitrate LR
3. Fill a 25-mL graduated mixing cylinder with 15 mL of sample.
4. Add the contents of one NitraVer 6 Reagent Powder Pillow to the cylinder. Stopper.
5. Press **TIMER>OK.** A 3-minute reaction period will begin.
6. Shake the cylinder vigorously during the three-minute timer.
7. When the timer expires, press **TIMER>OK** again. A 2-minute reaction period will begin.
8. When the timer expires, carefully pour 10 mL of the sample into a clean square sample cell. Do not transfer any cadmium particles to the sample cell.
9. **Prepared Sample:** Add the contents of one NitriVer 3 Nitrite Reagent Powder Pillow to the sample cell.
10. Press **TIMER>OK.** A 30-second reaction time will begin.
11. Cap and shake the sample cell gently during the 30-second timer. A pink color will develop if Nitrate is present.
12. Press **TIMER>OK.** A 15-minute reaction period will begin.
13. **Blank Preparation:** When the timer expires, fill a second square sample cell with 10 mL of original sample.
14. Insert the blank into the cell holder with the fill line facing right.
15. Press **ZERO**. The display will show: 0.0mg/L NO_3^--N
16. Insert the prepared sample into the cell holder with the fill line facing right. Press **READ**. Results are in mg/L NO_3^--N

Nitrogen, Nitrite
Method 8507

1. Press **STORED PROGRAMS**
2. Select the test: 371 N Nitrite LR PP
3. Fill a square sample cell with 10-mL of sample.
4. **Prepared Sample:** Add the contents of one NitriVer 3 Nitrite Reagent Powder Pillow. Swirl to dissolve. A pink color will develop if Nitrite is present.
5. Press **TIMER>OK.** A 20-second reaction time will begin.
6. **Blank Preparation:** When the timer expires, fill a second square sample cell with 10 mL of sample.
7. Wipe the blank and insert it into the cell holder with the fill line facing right. Press **ZERO**. The display will show: 0.000 mg/L NO_2^--N
8. Wipe the prepared sample and insert it into the cell holder with the fill line facing right. Press **READ**. Results are in mg/L NO_2--N.

Nitrogen, Ammonia
Method 8155

1. Press **STORED PROGRAMS**
2. Select the test: 385 N, Ammonia, Salic
3. **Prepared Sample:** Fill a square sample cell to the 10-mL mark with sample.
4. **Blank Preparation:** Fill a second square sample cell to the 10-mL mark with deionized water.
5. Add the contents of one Ammonia Salicylate Powder Pillow to each cell. Stopper and shake to dissolve.
6. Press **TIMER>OK.** A three-minute reaction period will begin.
7. When the timer expires, add the contents of one Ammonia Cyanurate Reagent Powder Pillow to each cell. Stopper and shake to dissolve.
8. Press **TIMER>OK.** A 15-minute reaction period will begin. A green color will develop if Ammonia-Nitrogen is present.
9. When the timer expires, insert the blank into the cell holder with the fill line facing right.
10. Press **ZERO**. The display will show: 0.00 mg/L NH_3-N
11. Wipe the sample and insert it into the cell holder with the fill line facing right.
12. Press **READ**. Results are in mg/L NH_3-N.

Phosphorus, Total
ICP Procedure

Sample Prep:

1. Lable 15 mL test tubes.
2. All samples need to be 2% HNO_3 by volume. Refrigerate for 12 hours after acid addition before running on ICP.

ICP running:

1. Power on computer.
2. Open WinLab32.
3. Turn on gases. Nitrogen should be greater than 100 psi. Gas tanks should have greater than 200 psi built up. Check gas level in tank is not empty.
4. In WinLab32, go to analysis → autosampler. In the plasma window the Nebulizer should be set to 0.50 and the RF Power set to 1500. Click Apply. Click the On button. ICP will not start unless the door to the plasma is shut.
5. Let machine warm up for 30 min before running.
6. To set up methods, click File → Open → Method. On the periodic table, use the preferred wavelength. Go to Settings. Select the Time to be Auto, the Delay to be 60 sec, and 3 replicates. (F1 gives help on all menus)
7. For Calibration, define standards and location. Enter the units and concentration values for your standards. For the blank, use 2% acid solution as your first standard. Equations should be Linear.
8. To enter samples, click Sample Info → Batch ID. Enter the sample ID. Right click to use column fill. The right click and column fill the location, starting with location 9 (or location of first sample). Click File → Save As → Sample File Info.
9. Wait for ICP to initialize optics.
10. The analyze samples, in Auto Analysis window, go to Results Data → Save. Under Analyze click Analyze All.
11. The Calibration should have results with RSD<1.
12. To see data click Examine → Data → Data Set
13. If emergency switch is tripped click Emergency Switch → System → Reset Emergency Plasma Off → OK (turn button on) → On (on Plasma Control)
14. To retrieve results, go to WinLab32-offline. Click File → Open → Method then Reproc → Data Set → Select Results
15. To shut down, turn plasma button to off. Go to Analysis→ Auto Sampler Up.

ICP Maintenance:

1. The black tube takes sample to machine. Change once a week. The red tube is the return. Change every few weeks. Release the clips between runs so tubing doesn't sit stretched.
2. To clean the injector and the torch, let sit in 2% acid solution overnight. After reinstalling the view must be realigned. To do so, click Tools → Spectrophotometer

Control. Align the view with the Mn solutions. Click Analysis → Auto Sampler → Go To: Location "X" where the Mn solution is located. Click OK on the Radial (plasma) when using the 10 ppm Mn solution and for Axial use the 1 ppm Mn solution. Between aligning the Radial and Axial views put Autosampler in Wash location (2% HNO_3) by Shift+F10.

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